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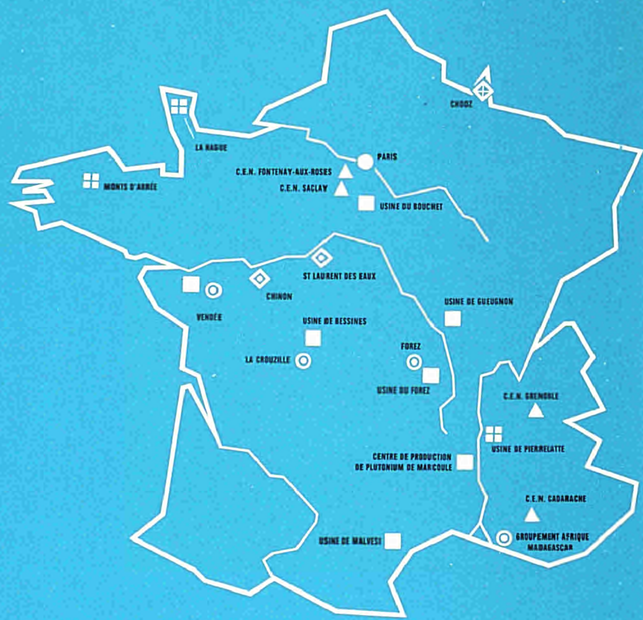
BULLETIN OF THE EUROPEAN ATOMIC ENERGY COMMUNITY

December 1964 Vol. III No 4

enable them to see things from the angle of those who are responsible for co-ordinating the setting up of a European nuclear industry. It should be pointed out that the concluding article of the present issue is concerned with precisely this vital aspect—co-ordination. It sketches out an automatic documentation system, the development of which has already attained an advanced stage and which, improved by a number of adaptations, promises to become a highly useful tool for the detailed analysis and comparison of all the European scientific and technical activities in progress in the field of nuclear energy. It might therefore serve to eliminate overlapping and duplication of effort once and for all.

It is certain that, while underscoring a number of standpoints common to all, the series of articles we are launching will at the same time bring out certain divergencies of opinion from one country to another, as well as particular trends dictated by local requirements. We may add that we think this desirable, since a community based on really democratic foundations will inevitably experience clashes of opinion from time to time. For discussion, provided that it is frank, cannot but light the way to rational solutions of the problems at issue.



Central administration

Scientific establishment

Industrial establishment

Establishment under construction

Mining division

EDF nuclear power plants

Franco-Belgian Nuclear Power Plant (Euratom Joint Enterprise)

Quarterly Information Bulletin of the European Atomic Energy Community (Euratom)

1964 - 4

The Community's mission is to create the conditions necessary for the speedy establishment and growth of nuclear industries in the member States and thereby contribute to the raising of living standards and the development of exchanges with other countries (Article 1 of the Treaty instituting the European Atomic Energy Community).

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With this issue, Euratom Bulletin launches a series of articles dealing with the atomic programmes pursued by the individual member states of the European Community.

The authors of these articles are not mere observers of the scene, but, occupying as they do key positions in the institutions which act as the mainspring of the nuclear programmes of the respective countries, they are particularly well-qualified to explain the decisions taken so far and to outline those which will sooner or later have to be made.

In this number, we start out by dealing with the nuclear activities of France, described in an account by the Director of Programmes at the French Atomic Energy Commission (CEA), followed by two articles, each covering a field in which Community activities are linked up with the national effort.

The first concerns an association between Euratom and the CEA aimed at the development of a device which is the key to an improvement in the economics of a family of reactors probably destined to play an important part in Europe, gas-graphite reactors.

The second relates to the solution of a problem which is bound to become progressively more acute with the increasing number of nuclear power plants, namely the disposal of fission products.

Our aim in publishing this series of articles on the national nuclear programmes is to provide our readers with an overall impression of the lines followed by the various countries of the European Community, and thus to

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The French atomic programme

H. DE LABOULAYE, *Head of the Programme Department, Commissariat à l'Energie Atomique, France*

In the majority of industrial countries, the launching of activities in the atomic field has been somewhat dependent on circumstances, since account had to be taken, in particular, of existing know-how and of available facilities with regard to special material and equipment.
Starting from situations having complex historical roots and in the creation of which the human factor had played an important part, the major national bodies for nuclear research thereafter endeavoured to map out their general policies on the basis of medium and long-term prospects and to modify accordingly the overall nature of their activities and the stress laid on various aspects of them.

Logic and foresight gradually reasserted themselves, but at this stage it often became apparent that, by virtue of intuitive selection and the elimination of blind alleys, the original policy was not so bad and ultimately required only minor alterations. This applies, I think, to the French nuclear programme.

The aims

The programme can at present be considered as following six main thrusts:

1. The design and construction of power plants;
2. The design and production of armaments;
3. Production studies and production of basic materials (uranium, uranium-235, plutonium, heavy water, etc.);
4. The production of radioisotopes and the use of radiation;
5. Basic and long-term research;
6. Radiological protection and nuclear safety.

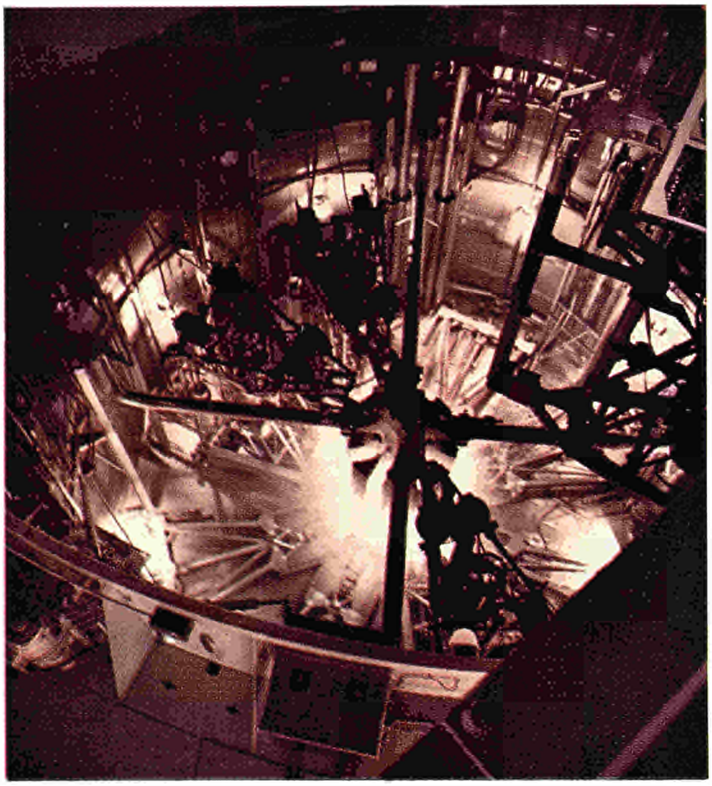
Rather than analyse each of these points in detail, it is our intention to make a few remarks on them which may be of interest to the Euratom Member States.

Design and construction of power plants

This section of the programme is aimed mainly at the development of electric power plants, since it is only with nuclear energy that Europe will be able to alleviate the ever-increasing burden of importing fuel from abroad. These plants will generate current at a lower cost than those run on conventional fuels.
Furthermore, France is also engaged on a programme of research into nuclear submarine propulsion units modelled on the ordinary-water enriched-uranium type of reactor, a land-based prototype of which went recently into service at the Cadarache Centre. Some preliminary work was begun on a small, very high temperature reactor for use in space travel, but it was recently shelved since the French and European space authorities had no immediate need for a reactor of this type.

At a time when the production of competitive nuclear electricity is in the offing, a seemingly sterile quarrel is blowing up between different families of reactors. Can it honestly be maintained in 1964 that the technical and economic attractions of one of these reactor families, using, say, enriched uranium and ordinary water, or graphite and compressed gas, or heavy water with various coolants, will in the future be so much greater than that of the others? Who remembers now that the first automobile to travel at 100 km/h was run on electricity, or that the first to pass the 120 km/h mark was steamdriven?
Round about 1958, people were swearing by the Calder Hall power plant[1], now it is Dresden or Oyster Creek[2], and who can say but that tomorrow it may not be Douglas Point[3], unless it is EDF 4 or EL 5, on which all hopes will be pinned?
In point of fact, the economic conditions peculiar to each region are such that each of these types of power plant might prove the most suitable, provided that it is vigorously developed in an effort to improve on present techniques, a reduction in cost being the constant aim in view.
Following the example of the British, the French, after considerable deliberation, plumped for the graphite/compressed-gas type of reactor for running their nuclear power plants, the first being built with a steel vessel. In EDF 3, however, it was decided to use pre-stressed concrete, which had in the meantime been successfully experimented with in the Marcoule G 2 and G 3 reactors. The EDF 3 (480 MW) plant, completion of which is scheduled for 1966, will thus be the head of the French natural-uranium/graphite/CO_2 reactor family. In EDF 4 (500 MW), construction of which has just been commenced, the heat exchangers will be built into the vessel, the resultant compactness leading to a reduction in costs and greater safety.
Other plants based on EDF 4 are planned, but their number will depend on the results obtained with the semi-prototype EDF 5 plant, construction work on which should be given the go-ahead at the beginning of 1965 if the preliminary studies now under way prove satisfactory. While constructed on the natural-uranium/graphite/

1. Natural uranium, graphite and compressed gas.
2. Enriched uranium and ordinary water.
3. Natural uranium and heavy water.

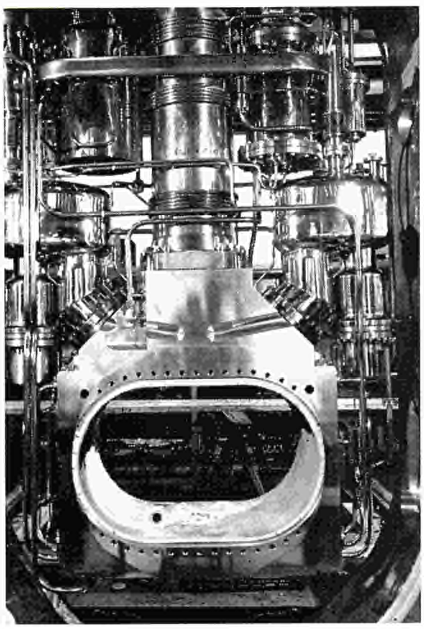


Cadarache: the Pégase *fuel-testing pile.*
The bogies (loop-carriers) which converge on the core can be seen at the bottom of the pool.

compressed CO_2 basis, its annular-shaped fuel will differ appreciably from that used in previous plants and should permit a marked improvement in the heat exchange and unloading procedure owing to the reduced number of channels. If EDF 5 is a success, it will act as the basis for future French gas-graphite reactors.
Even with EDF 4 there is every hope that a cost per kWh can be reached which is lower than that of conventional power plants, so that about one new nuclear 500 MW plant could be installed every year in France during the country's five-year plan (1966-70).
If the French are so sure that in the graphite reactor they have hit upon a good solution to their energy problems, it may be asked, then why do they attach so much importance to developing two other types of reactor, using heavy water and fast neutrons? The reason is much less a desire to determine the most favourable short-term economic conditions but rather lies in longer-term considerations regarding uranium economy, for it is no secret that the free world's known economic uranium reserves are at present extremely limited, although it is hoped that prospecting techniques will one day be improved, as was the case with oil. These reserves could only be stepped up by accepting the fact that future power plants would have to be run on more expensive uranium, but this is acceptable only if the proportion of the cost per kWh made up by the cost of natural uranium remains low. On this basis, each ton of natural uranium would be required to produce a large number of kWh. However, in the absence of plutonium recycling, neither graphite-gas reactors nor those run on enriched uranium and ordinary water are very suitable from this point of view. Heavy water reactors, on the other hand, which are extremely efficient with regard to the production and utilisation of plutonium, fulfil this requirement. What plutonium recycling in non-breeder reactors exactly involves has not yet been clearly established, so France has drawn up a major research contract with Euratom to investigate the matter further. The Canadians, Swedes, Germans, Swiss and more recently the British, to mention only a few, have been attracted by heavy-water reactors. France had already carried out some experiments on them right from the beginning of her nuclear activities. The EL 4 (73 MW) plant is being built in Brittany and is to start producing power by the end of 1966 or early 1967. It is cooled by compressed gas and is of tubular structure. Cooling systems using heavy water (Canada, Sweden), fog (Britain, Italy) or organic liquid (Euratom, Canada) are, we feel, only variations on one main basic type, on which it is well worth experimenting for purposes of comparison, but between which any economic rivalry is equally premature as yet. It is for this reason that France attaches importance to being associated with the *Orgel* research project at Ispra and to following the Canadian programme, activities which are complementary to EL 4, developed by France herself. The French programme provides for the construction of a prototype power plant of some 300 MWe, based on EL 4, to begin around 1968. It will not be before 1970, therefore, that France will finally decide whether to continue to base the entire thermal neutron reactor programme on the gas-graphite concept or to include a vast heavy water reactor project in the programme.
With regard to ordinary water plants, France is acquiring experience with these by its participation in the joint enterprise at Chooz (Franco-Belgian 266 MWe power plant built under Euratom's aegis) and also by its submarine propulsion units and the thermodynamic work being carried out at Grenoble. However, no pressing need is felt at present to make this the crux of the entire programme.

Magnetic mirror and ion injection device (M.M.I.I.) used for research on controlled thermonuclear fusion (in association with Euratom).

180 litre hydrogen bubble-chamber. This apparatus, the largest of this type in operation in Europe, makes it possible to see the trajectories of very high energy particles. Millions of photographs of these trajectories have been taken since the chamber was commissioned in July 1963.



While it is not good for a nation to allow such a vital sector as electric power to depend on one single source of fuel, a careful analysis of the cost price of these power plants under European conditions, allowances being made for the investment in the first fuel loading, shows them not to possess such an indisputable economic advantage as certain publicity campaigns would have one imagine. Finally, they are much more dependent on an increase in the cost of natural uranium than the heavy water plants, say, and produce less plutonium.

Breeder reactors will sooner or later enter into the scheme of things in the field of atomic energy and it is for this reason that the Euratom member countries, in particular France and Germany, are devoting a considerable amount of research and development work to breeders under Euratom contracts of association. The *Rapsodie* experimental reactor, the *Masurca* critical model and the impressive sodium circuits at the Cadarache nuclear centre form the mainstays of these studies. If *Rapsodie* justifies present hopes, it will perhaps be possible to build a true prototype of a fast neutron plant capable of producing electricity by about 1969, and after that, even if breeder reactors are developed rapidly, the rate of this development in Europe will depend on two factors:

1. the extent to which their cost price and running costs can be reduced;
2. the date at which there will be a shortage of cheap uranium, the rate at which its price rises, and the level up to which the price increase would be acceptable (in particular, in heavy water reactors).

It is difficult to understand why, once they have been developed, a production cost could not be achieved with breeder reactors which is at least as low as other power-producing reactors, since, among other considerations, very high-quality steam is obtained with them. When this stage is reached, an effort will be made to increase the number of such reactors, as a result of which a high proportion of thermal-neutron reactors will continue to be built for a long time in order to feed them with plutonium at an adequate rate.

Since she has adopted what she feels to be a balanced programme of three reactor types having complementary characteristics, France does not at the moment intend to engage in any activities on other types, such as high temperature gas reactors, but at the same time is fully aware of their potential interest and is following their progress by participating in the *Dragon* and *AVR* projects.

As an eminent American expert has said, "a nuclear reactor is designed round its fuel". The French activities aimed at the development of nuclear fuels which can withstand thermal cycling and radiations are therefore and will continue to be appreciable. Everything conceivable with regard to nuclear fuels—cores made of alloys of natural or enriched uranium or plutonium, sintered oxide pellets or carbides, studies on carbonitrides, on fine dispersions, stainless steel canning, magnesium, aluminium, zirconium or even beryllium alloys, rod, tube, pin and plate configurations—is being studied, tested, used and manufactured. At the present stage most of the basic research into and development of techniques is carried out by the CEA, industrial firms (e.g. CERCA, SICN) assuming responsibility for bulk manufacture.

A major requisite of fuel elements and reactor components is that they should be able to withstand the sometimes very high radiation fluxes to which they are exposed. However desirable it may be that French industrial firms gradually equip themselves for the mechanical and thermodynamic tests now being carried out by the CEA, it is difficult to imagine that they would be prepared to foot the bill for the construction of all the materials testing reactors required for irradiation experiments. Holding that this constitutes one of the cornerstones of progress in the nuclear field, the CEA has of its own volition launched an ambitious programme devoted to such reactors. After construction of EL 3 (15 MW) which went into operation in 1957, and the two small swimming-pool reactors *Mélusine* and *Triton* (1958 and 1959), it was decided to equip its Grenoble Centre with the interesting *Siloé* reactor (15 MW), the most powerful swimming-pool in the world, experimental access to which is remarkably easy. In 1963 Cadarache was provided with a unique type of reactor in the form of *Pégase* (30 MW) with which full-scale irradiations of gas-reactor fuel elements can be carried out in eight mobile loops. In 1966 Saclay will be fitted out with *Osiris*, a powerful (50 MW) high semi-fast neutron flux reactor based on *Siloé* and offering considerable flexibility in use. Furthermore, irradiations are now under way in the HFR reactor at Petten and the BR 2 reactor at Mol. *Rapsodie* itself will complete the chain, providing facilities for testing fuels for fast neutron reactors.

Each materials testing reactor is provided with the high activity laboratories necessary for the examination of irradiated substances.

The EDF Avoine site near Chinon; from right to left: the EDF 1, EDF 2 and EDF 3 reactors.

The design and production of armaments

It would be flying in the face of the facts to omit to mention the very important part played by that section of the French nuclear programme devoted to the production of armaments. The problems relating to fission weapons can be regarded as mastered and the programme is mainly concentrated on much more complex systems based on the fusion of light nuclei. This resulted in the decision to produce a certain number of special basic materials which would doubtless not have been manufactured otherwise, including, primarily, highly enriched uranium-235 and low burn-up plutonium, to be produced at Pierrelatte and Marcoule respectively, but also more specific products such as tritium and lithium-6.

Whatever one might think of the French decision, it cannot be denied that research into military applications has indirectly resulted in considerable progress being made with regard to nuclear and para-nuclear techniques, such as calculation of the dynamics of complex systems at high temperatures and pressures, ultra-rapid electronic detection (nanosecond range), neutron measurements on fast critical assemblies, criticality detection, i.e. safety, special metallurgy, technology, etc.

Production studies and production of basic materials

Natural uranium: France is one of the very few countries in Western Europe which produces an appreciable quantity of uranium from its own subsoil (a little over 1000 t/year). In addition, the CEA is working the Mounana deposit in the Gabon Republic and also extracts a little uranium from the uranothorianite in Madagascar. Nonetheless the present ease with which requirements are met should not give rise to any illusions, and, allowing for the known reserves, it would be unreasonable to expect a major increase in the quantity produced by metropolitan France. In twenty years or so Europe will be faced with a very grave problem as to how to supply its nuclear programme with basic materials at a satisfactory price, as was stressed by the recent report published by the Consultative Committee of the Euratom Supply Agency[4], and it is the French view that preliminary arrangements must be made even now for the prospecting work involved and the necessary planning.

Ore-concentration and processing plants (Bouchet and Malvési) are necessary for the production of uranium. These plants are already in existence and are not to be expanded for the time being.

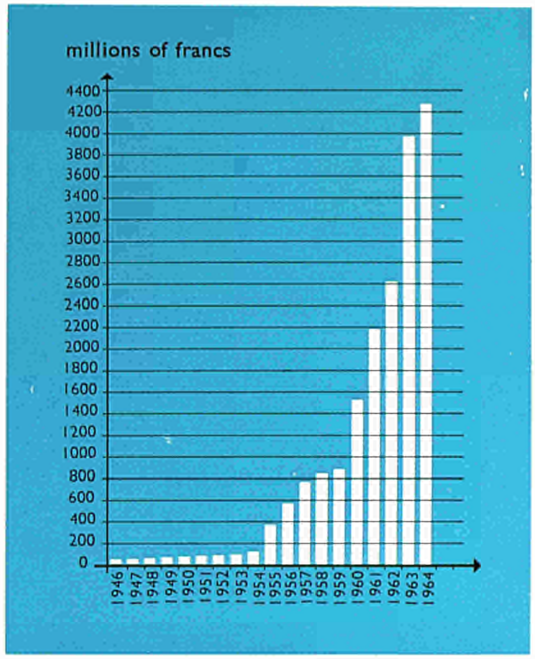
Enriched uranium: It has been seen that the French nuclear power plant programme is not based on enriched uranium reactors, so the output of the isotope separation plant at Pierrelatte will mainly be earmarked for military requirements. In view of its limited

4. "The long-term problem of uranium resources and supply", 1963.

scope, it would be impossible for it to supply even only slightly enriched uranium at prices comparable to that supplied by the US.
However, if an appreciable section of the European nuclear programme had to be based on enriched uranium reactor types in about twenty years' time, and if this were the case throughout the rest of the world, the existing American plants, gigantic as they may be, would not be able to meet the demand. In this case the construction of a large European low-enrichment separation plant might appear an attractive proposition and the experience acquired in the meantime at Pierrelatte would prove extremely useful. For such large-scale production, the gas-diffusion method would seem to beat ultra-centrifugation hands down, but a limited amount of research is nonetheless still being carried out on this technique at Grenoble.
Plutonium: The output of the EDF reactors should be sufficient to keep a fast neutron reactor programme supplied. The plutonium investment for the first loading is, of course, considerable in fast reactors (several tons for a power reactor of several hundred MW), but, as has already been mentioned, the French fast neutron programme will get under way relatively slowly. No bottleneck is therefore to be expected in this sector barring unforeseen eventualities.
Some of this plutonium could be extracted at the Marcoule plant and some at the La Hague plant, the first section of which will be completed by 1966. These plants should be able to satisfy most of the production requirements up to and beyond 1970, and no others are planned for the moment.
A certain number of minor installations will be necessary for reprocessing the cores of *Rapsodie* and the materials testing reactors.
Other materials: Nuclear graphite is now being produced commercially *(Péchiney)*, while heavy water will be produced in a few years by a small plant at Mazingarbe (Pas de Calais) using the NH_3-H_2 exchange method.

Production and use of radioisotopes

This is a modest field from the point of view of the investments involved, but one which offers a constantly increasing number of possible applications.
In 1963 the CEA supplied 35,500 consignments of radioelements, 6,500 of them to foreign countries, and a 30% annual increase in demand is expected. An agreement has been concluded with the Belgian *Nuclear Energy Study Centre* and the Italian firm of *Sorin* aimed at the co-ordination of the three countries' production facilities.
Research into the separation of fission products forms the object of a research contract drawn up with Euratom[5] and the first prototypes are expected soon, although large-scale production is not envisaged until such time as an adequate market is ensured. An effort is being made to help industrial firms (*Centre lyonnais d'applications atomiques, l'Atome industriel*, etc.) to promote the industrial applications of radioelements and large radioactive sources. Hospitals and agricultural institutes are also encouraged in their research, which is conducted parallel



Growth of nuclear programmes since their inception

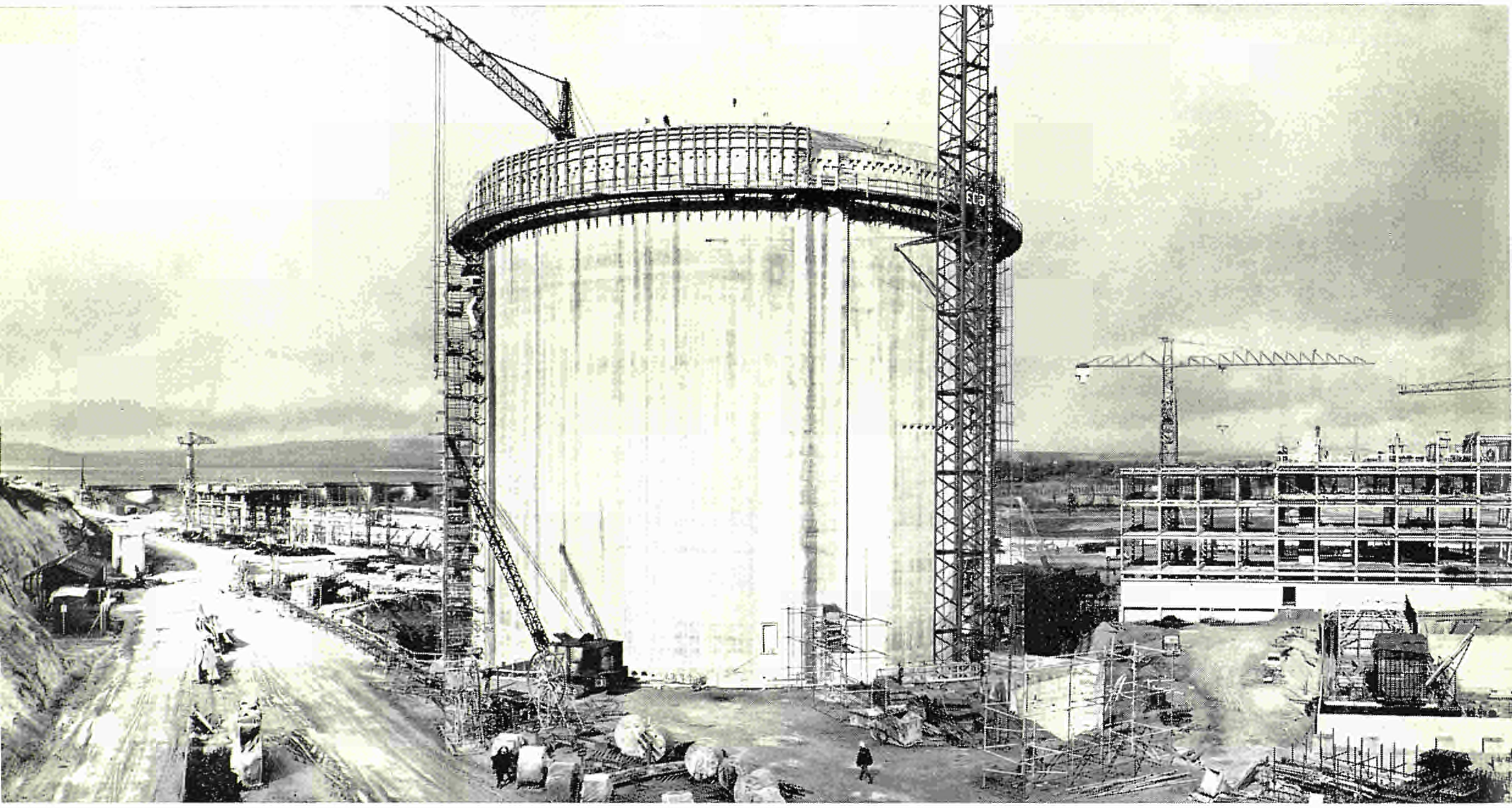
N.B.: As of 1960, the figure given includes funds entered in the defence budget to cover expenses of a more immediately military nature.

List of French nuclear reactors in operation or planned

I. Research and test reactors

Name	Location	Crit. date	Max. flux nth/cm²/sec.	Therm. power max. kW	TYPE: Fuel	TYPE: Moderat.	TYPE: Coolant	Purpose
EL 1 (Zoé)	Fontenay-aux-Roses	15.12.48	10^{12}	150	nat. UO_2	D_2O	D_2O	Research
EL 2	Saclay	21.10.52	10^{13}	2,500	natural U	D_2O	CO_2	Research and production of radioelements
EL 3	Saclay	4. 7.57	10^{14}	17,500	slightly enriched U	D_2O	D_2O	Research, materials testing and radioelement production
Mélusine	Grenoble	1. 7.58	10^{13}	2,000	enriched U	H_2O sw. pool	H_2O	Research
Triton	Fontenay-aux-Roses	30. 6.59	10^{13}	2,000	enriched U	H_2O sw. pool	H_2O	Shielding studies
Minerve	Fontenay-aux-Roses	29. 9.59	10^{11}	low	enriched U	H_2O sw. pool	nil	Analysis of purity of materials
Ulysse	Saclay	23. 7.61	1.4×10^{12}	100	enriched U	H_2O	H_2O	Training
Siloé	Grenoble	18. 3.63	10^{14}	15,000	enriched U	H_2O sw. pool	H_2O	Research
Pégase	Cadarache	4. 4.63	1.5×10^{14}	30,000	enriched U	H_2O	H_2O	Tests on gas-reactor fuels
Cabri	Cadarache	21.12.63			enriched U	H_2O	H_2O	Safety studies
Harmonie	Cadarache	1965	10^{13}	2	enriched U		air	Reactor as source for neutron experiments
Osiris	Saclay	1966	2.5×10^{14}	50,000	enriched U	H_2O	H_2O	Materials testing

5. See the article on page 12 of this issue.



Brennilis (Finistère). Construction site of the EL 4 heavy-water reactor (26 February 1964).

to the research being carried out by the CEA itself on the medical and agricultural uses of radioisotopes.

Basic and long-term research

Twenty years ago, nuclear physics and nuclear energy were two closely interlocked fields, since the interaction of neutrons and low-energy radiations with nuclei constituted one of the essential unknown features of the problem and the detection of these particles had not been fully mastered. However, these two fields have since diverged considerably, and the development of power plants is now dominated by technological and metallurgical problems which have nothing to do with nuclear science, while nuclear physics is concerned with the study of phenomena which are not encountered in reactors. This is not the case with solid state physics, radiation chemistry and physico-chemistry, for which nuclear applications are constantly being found.

For this reason the French have adopted a varied policy in this field. The CEA is maintaining a highly qualified nucleus of high-energy physicists, who are working on the *Saturn* 3 GeV proton synchrotron at Saclay, but they will no doubt only be responsible for designing the 15 GeV device planned under the country's next five-year plan. On the other hand, they will continue to supervise the construction and operation of smaller devices such as the 300 MeV electron linear accelerator due to be built at Saclay and another of 50 MeV and very high intensity scheduled for installation at Cadarache. However, if the very high flux research reactor which the solid

state physicists are calling for is built at Grenoble, the CEA will certainly act as the administrating authority.
The attitude of the CEA toward very long-term studies into plasma physics and controlled fusion is fairly comparable to that toward the basic research programme. The bulk of the French activities in these fields is carried out in collaboration with Euratom at the Fontenay-aux-Roses centre. Other research has been undertaken by the CEA, the EDF and the IFP[6] into energy conversion using magneto-hydrodynamic techniques.
Finally, a very competent CEA team is engaged on basic biological research on cells and even molecules, including the effect of radiation on living matter.
It is felt that the existence of basic and applied research side by side in the same centres provides a valuable mutual stimulus.

List of French nuclear reactors in operation or planned

II. Critical assemblies

Name	Location	Crit. date	Max. flux nth/cm²/sec.	Therm. power max. kW	TYPE			Elec. power kW	Purpose
					Fuel	Moderat.	Coolant		
Aquilon	Saclay	11. 8.56	10[illegible]	low	nat. U	D_2O	nil		Lattice studies
Alizé	Saclay	18. 6.59	5 × 10[illegible]	low	enriched U	H_2O	nil		Lattice studies
Marius	Marcoule	7. 1.60	10[illegible]	0.1	nat. or enrich. U	graph.	nil		Lattice studies
Peggy	Cadarache	2. 2.61	5 × 10[illegible]	low	enriched U	H_2O	nil		Critical mock-up of Pégase
Rachel		4.61		low	Pu	nil	nil		Fast neutron studies
Alecto I-II	Saclay	8.11.61 28.12.62	5 × 10[illegible]	low	Pu & U^{235} in solut.	H_2O	nil		Criticality studies
Azur	Cadarache	9. 4.62			enriched U	H_2O	nil		Critical mock-up of prototype for submarine
César	Cadarache	1964		0.1	nat. or enriched U	graph.			Lattice studies
Masurca	Cadarache	1966		low	enriched Pu and U		air		Critical mock-up of fast neutron pile

III. Experimental and prototype reactors

Name	Location	Crit. date	Max. flux nth/cm²/sec.	Therm. power max. kW	TYPE			Elec. power kW	Purpose
					Fuel	Moderat.	Coolant		
Prototype for submarine (P.A.T.)	Cadarache	24. 8.64			enriched U	H_2O	H_2O		Submarine propulsion experiments
Rapsodie	Cadarache	1966	2 × 10[illegible]	20,000	enriched Pu and U	nil	sodium		Fast neutron breeder reactor
EL 4	Brennilis (Finistère)	1966		240,000	UO_2	D_2O	CO_2	73,000	Electricity production

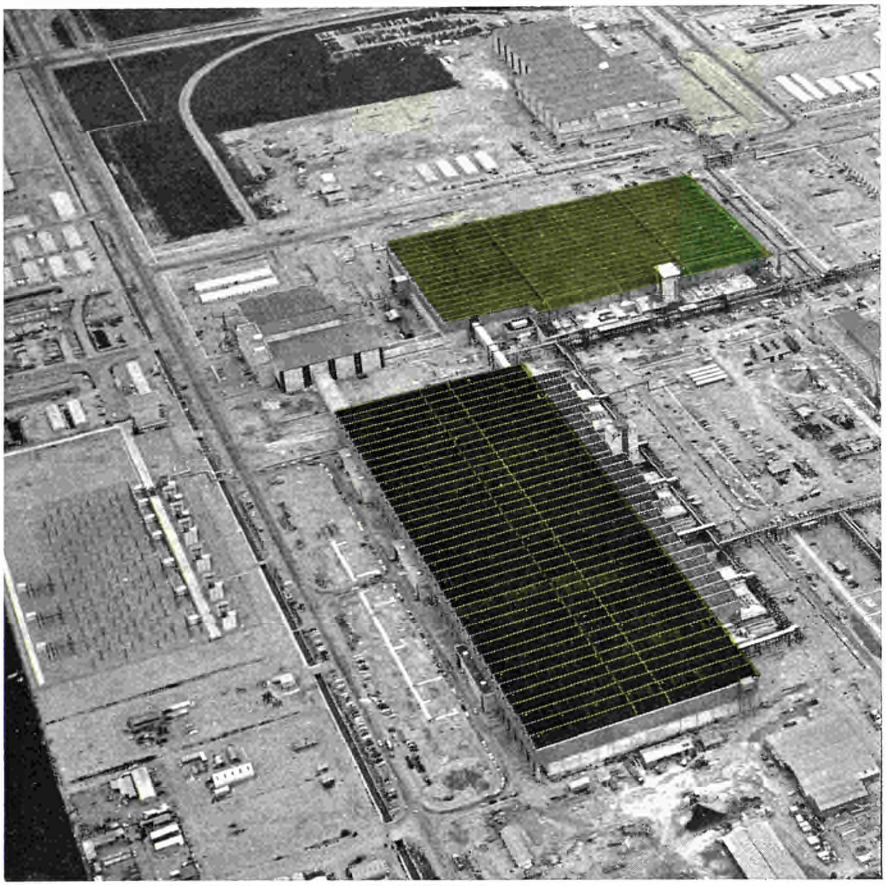
Health protection and plant safety

The atomic industries will for a long time only be able to permit a minute rate of accidents due to radiation in view of the sensitivity of public opinion on the subject. In addition, it must reduce the risk of a major criticality accident.
A considerable amount of work in France has therefore been devoted to the exact definition of health protection standards (under Euratom contract) and to the evaluation of the probability of accidents and their consequences. In addition, numerous theoretical and experimental studies are being conducted on criticality. The only dynamic test pile in existence in Europe, *Cabri* at Caradache, is used to simulate an abrupt power surge in a reactor and could conceivably be used in an international programme.

Facilities

A vast infrastructure of special facilities is required for pursuing the aims outlined above and include:
– three experimental or prototype reactors (EL 4, *Rapsodie*, land-based prototype);
– 21 reactors for research, materials-testing and critical experiments;
– several very high activity laboratories; two of them being used for the study of irradiated fuels;
– about twenty particle accelerators;
– one IBM *Stretch*, two IBM 7094 and numerous smaller computers; one analog computation laboratory and a well-equipped electronics section;
– several plants for the production of materials and nuclear fuels;
– two irradiated fuel processing plants.
All these facilities are grouped in four nuclear study centres:
– Saclay (staff of about 5000);
– Fontenay (about 1500);
– Grenoble (about 1200);
– Cadarache (being rapidly expanded up to about 2500);
– five centres for the production of special materials;
– three mines complete with concentration plants;
– one prototype EDF power plant (Brennilis) for EL 4;
– three EDF power plant sites:
  – Chinon
  – St. Laurent des Eaux
  – Chooz;
– some military research centres.
A few figures will give an indication of the amount of money involved in these activities. At Saclay and Cadarache about one billion francs has been invested in each of the centres, while investments in Grenoble and Fontenay run to 200 million respectively. The EDF site at Chinon (EDF 1, EDF 2 and EDF 3 plants) will represent an investment of about a billion and a half francs in 1966. The parliamentary debate in 1962 revealed that a budget of five billion had been earmarked for the Pierrelatte plant. A figure of more than a billion francs is also to be invested in the plutonium-producing centre at Marcoule.
The 1964 budget of the CEA alone totalled 4,290,000,000 francs, excluding the French contribution to the financing of Euratom (135 million francs, or 30% of the total Euratom budget). Again this figure does not represent the entire French effort in the nuclear field since it does not include the financing of the construction of power plants by the EDF or industrial research and

6. *Institut Français des Pétroles.*



Uranium isotope separation plant at Pierrelatte. In the foreground, the low-enrichment plant; behind it the medium-enrichment plant.

Mock-up of the Rapsodie fast-neutron experimental reactor core.

development activities. The CEA budget for 1964 also includes some 88 million francs paid to France by Euratom for participation in various contracts of association, etc.

Although no decision has been taken on the subject, it seems likely that this budget will continue to increase at a faster rate than the gross national product until the end of the present decade.

Setting aside items covered by the defence budget, the CEA budget breaks down as follows:

35% for the design and construction of power plants[7];

29% for production studies and the production of basic materials;

2.5% for the production of radioisotopes;

14% for basic and long-term research;

8.5% for health protection and plant safety;

2% for training and various technical activities;

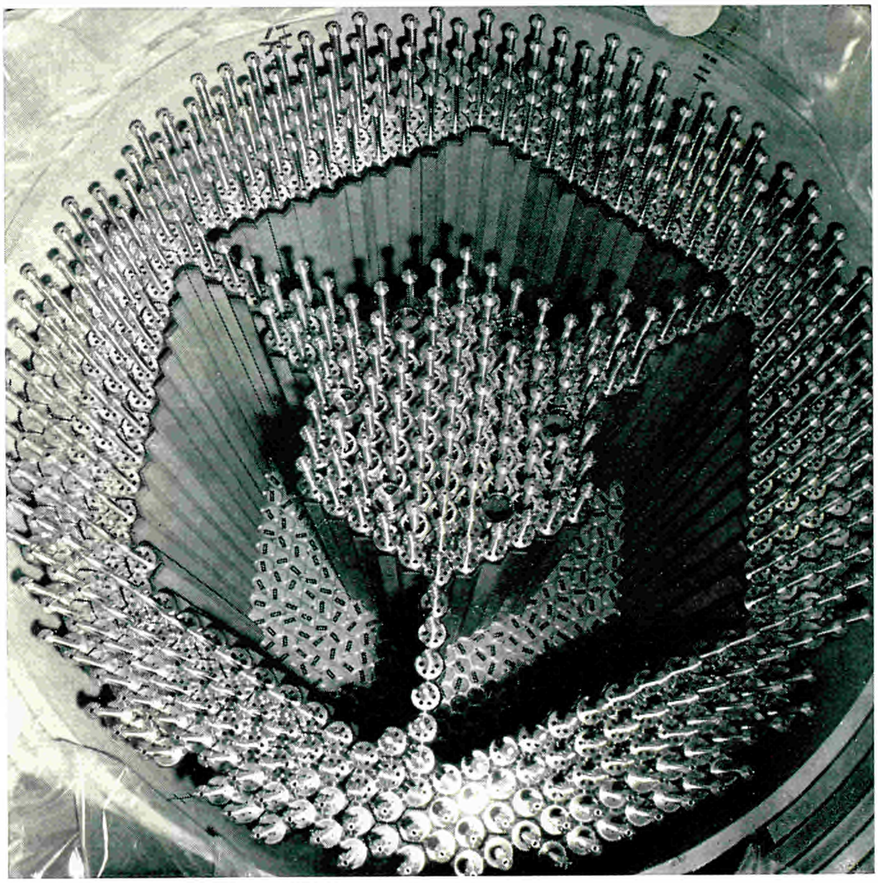
9% for financial charges, accommodation, and the operation of the central administration, the finances for the operation of the research centres being allocated in proportion to the activities on which they are engaged.

It is difficult to give an exact figure for the personnel in France engaged on the development of nuclear energy owing to its vast ramifications in industry, but by the end of 1964 the CEA will have more than 27,000 employees on its payroll, not counting the persons directly employed by the EDF in this field.

7. Excluding the EDF budget for power plants.

Conclusion

The effective execution of a balanced nuclear research programme obviously calls for intelligent planning and considerable financial resources, but, as the situation in Canada has shown, perseverance also plays a part. A narrow path must be taken between two equally dangerous rocks—that of shutting one's eyes to one's neighbour's successes and that of only accepting his solutions as valid. This lack of self-confidence was unknown in the industrial Europe of the nineteenth century. Swiss watches, Dutch electronics, Swedish steel and German optics are there to remind us of what industrious and tenacious peoples once achieved on their own. Will Europeans of the nuclear age be less intrepid?



List of French nuclear reactors in operation or planned

IV. Power reactors

Name	Location	Crit. date	Max. flux nth/cm²/sec.	Therm. power max. kW	TYPE			Elec. power kW	Purpose
					Fuel	Moderat.	Cool-ant		
G 1	Marcoule	7. 1.56	5×10^{12}	42,000	Nat. U 100 t.	graphite 1,200 t.	air press. atm.	3,000	Production of Pu and electricity
G 2	Marcoule	21. 6.58	2.5×10^{12}	250,000	Nat. U 150 t.	graphite 1,200 t.	CO_2 15 bars	40,000	Production of Pu and electricity
G 3	Marcoule	11. 6.59	2.5×10^{12}	250,000	Nat. U 150 t.	graphite 1,200 t.	CO_2 15 bars	40,000	Production of Pu and electricity
EDF 1	Chinon	16. 9.62	4.5×10^{12}	300,000	Nat. U 150 t.	graphite	CO_2 25 bars	70,000	Production of electricity
EDF 2	Chinon	1964		800,000	Nat. U 250 t.	graphite	CO_2 25 bars	200,000	Production of electricity
EDF 3	Chinon	1966		1,560,000	Nat. U 410 t.	graphite	CO_2	480,000	Production of electricity
EDF 4	St. Laurent-des-Eaux	1968		1,650,000	Nat. U 410 t.	graphite	CO_2	500,000	Production of electricity
Franco-Belgian power plant (SENA)	Chooz	1966		825,000	enriched UO_2	H_2O	H_2O	266,000	Production of electricity

Whatever their operational purpose and their type, reactors are sources of fission products. What is to be done with these radioactive products which will be turned out in enormous quantities as more and more reactors are built all over the world? One solution to the problem is to store the products in solid form. Another consists in converting them into useful sources of radiation or heat.

EUBU 3-22

The problem of fission products

ELIMINATION OR RECOVERY ?

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The heading "fission products" covers the products resulting from the nuclear fission of uranium.

It is well known that the fission of the uranium atom nucleus consists in its division under the impact of slow neutrons into two unstable fragments, the sum of whose charges is equal to 92. It can be represented schematically in the following form:

$$ {}_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{92}U^{236} \begin{array}{l} \nearrow x \\ \searrow y \end{array} + \simeq 2{,}46n + 200 \text{ MeV} $$

The fragments have a considerable excess of neutrons and are transformed by a series of ß-emissions into progressively stabler nuclides. All of these decay chains thus lead either to stable isotopes or to long-lived substances which accumulate during pile operation.

In order to give a more complete picture of the substances formed in a pile, it should be added that the substances which accumulate in this way all have a neutron capture cross-section, which will give rise to additional radioactive substances in quantities proportional to the burnup.

Fission may occur in many ways, i.e. *x* and *y* may have widely varying masses, ranging from 72 for germanium to 162 for dysprosium.

More than 200 different nuclides originating in the fission of uranium-235 have been identified.

The fission products with which we are mainly concerned, are those with a long half-life, such as strontium-90, caesium-137 and prometheum-147.

In nuclear reactors, the fission products are generally retained in the fuel elements. They become separated from them during the reprocessing of the fuel, an operation whose principal aim is the extraction of the unused uranium and the plutonium produced, and which consists in dissolving the irradiated fuel by means of acids, generally nitric acid alone. In this way a solution is obtained which is extractable by an organic solvent such as tributyl phosphate, the most commonly used hitherto.

Thus, once the uranium and the plutonium have been extracted, the residual solutions contain the greater part of the initial fission products.

These solutions are concentrated either under vacuum (British method) giving a 6 or 7 N solution in nitric acid, or by destroying the nitric acid by the addition of formol (French method) giving a 2 or 3 N solution in acid. The composition of these solutions varies greatly because many conditions may differ initially: there may or may not be chemical dissolution of the aluminium cladding, the uranium may be pure or alloyed, etc.

What happens to these fission products? The number of reactors in the world is continually increasing, and whatever their operational aim and type they generate fission products in enormous quantities. A major problem raised by fission products is therefore their storage. At present most countries possessing nuclear reactors make use of liquid storage in stainless steel vessels located immediately beside the fuel reprocessing plants.

Long-term storage

At present most countries consider that this type of storage is good enough in the medium term. According to many estimates it is the least expensive method (about $200 per ton of uranium processed). Nonetheless it is scarcely likely, mainly for safety reasons, that this method will be found adequate in future.

Two new avenues are now being actively explored:

1. putting the fission products into solid form;
2. separating the fission products.

Putting into solid form

The idea of putting the fission products into insoluble solid form has always appealed to research scientists. Many projects have been carried out either by direct calcination or by the use of additives and vitrification. The only industrial-type plant which has come into being hitherto is the fluidisation plant at Idaho Falls, where the cost price is about the same as that of the fission product separation process. At present it has the major drawback of putting all the fission products into an unusable final form, at a time when important uses are beginning to emerge.

The separation of the fission products

The first person to call attention to the value of this method was Glueckauf who, in 1955, estimated that an annual world consumption of 1,000 tons of nuclear fuel would lead to a stock of fission wastes more

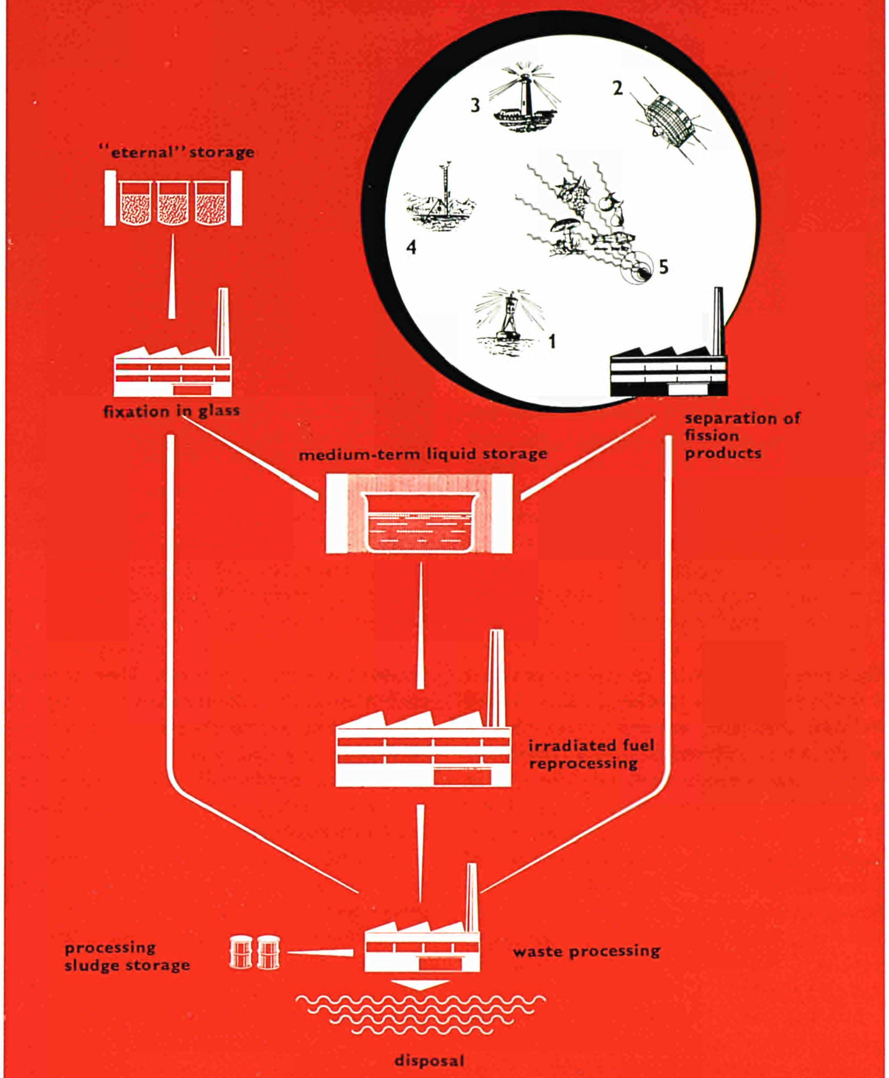


Figure 1: Possible solutions to the problem of fission products. (A few possible applications of fission products are shown in the white circle: 1. Buoy; 2. Satellite; 3. Lighthouse; 4. Meteorological station; 5. Irradiator).

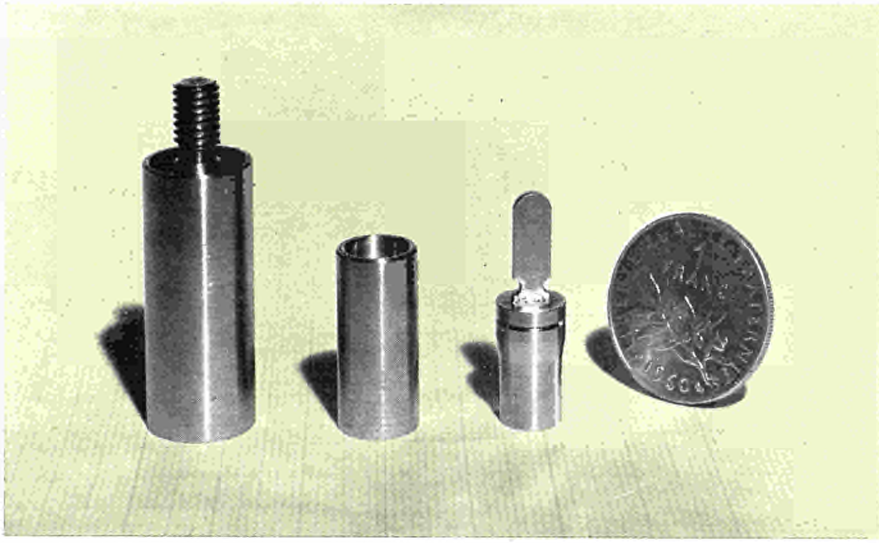


Figure 2: Caesium-137 irradiation sources.

than one year old with an activity of about 3×10^{11} MeV-curie (1 MeV-curie = 0.0059 W). At this level a state of equilibrium would be established between radioactive decay and new production. If this stock were dispersed uniformly in the world's sea-water it would give rise to a specific activity about equal to that already present in the form of potassium-40. But if the nuclides strontium-90 and caesium-137, which have the longest half-lives, were first removed from these residues, the equilibrium level would be reduced to 1/1000 of the previous value, while from the biological standpoint the gain would be much more important still since the toxicity of strontium-90 is about 25 times greater than that of the other fission products.

But this hypothesis was too optimistic and in the course of recent years there has become apparent an ever greater reluctance to dump large quantities of radioactive elements in the sea.

A variant of this method was suggested at Vienna in 1962; it envisaged the elimination of caesium-137 and strontium-90 with a decontamination factor of at least 10^4, i.e. leaving only one ten-thousandth of the initial quantity, followed by a conventional effluent treatment after a storage period of between 10 and 20 years. The Hanford centre recently put forward an original solution adapted to the particular conditions of this locality and consisting in a partial combination of the two basic methods, i.e. calcination and separation. The Hanford stock is of the following two types:

– More than half consists of neutral solutions several years old contained in million-gallon mild steel vessels.

– The other part consists of fresh solutions, generally nitric acid, and stored in stainless steel tanks.

The present project consists in separating out all the caesium and all the strontium from the other fission products by chemical means and fixing them separately on artificial zeolites contained in receptacles with a unit load of some hundreds of thousands of curies. These receptacles will be plunged in a former stripping pond and cooled down. The effluents and the remaining solutions, which will have become non-selfheating, would be dry-stored in former storage containers, a method which is considered as reliable in view of the desert-type climate of the region.

This method clearly has the following advantages: firstly the dangerous materials (strontium and caesium) will be easy to monitor and secondly they will always be easy to recover; they will not be irretrievably lost as in the vitrification process.

Chemical methods of separating the fission products

The recovery of the long-lived fission products has been the subject of continuous study for some years.

With caesium, four techniques may be distinguished, i.e. precipitation by phosphotungstic acid, ion exchange by heteropoly acid salts, solvent extraction and fixation on clinoptilolite; caesium can be extracted by "BAMBP" [4-*sec*–butyl–2(α-methylbenzyl) phenol].

In France the recovery of caesium-137 has been developed with the dual aim of producing this radioisotope and of obtaining a sufficiently good decontamination factor to provide a long-term solution to the storage problem. The method used is precipitation by phosphotungstic acid or better still the exchange of the caesium with ammonium phosphotungstate by which it is possible in two exchange processes to obtain a decontamination factor of 10^4.

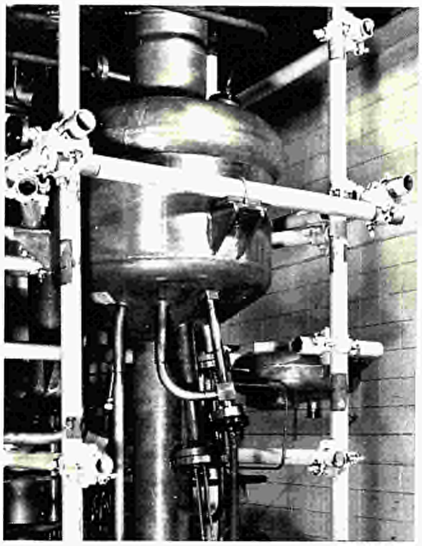


Figure 3: Pilot cell for separation of fission products — evaporator. (Saclay Centre, France)

A pilot plant based on the first method, with an annual capacity of several kilocuries, is at present operating at Saclay.
A second plant, based on exchange on a combined ammonium phosphotungstate—zirconium phosphotungstate exchanger, is in course of construction.
With strontium it is possible to proceed either by solvent extraction (as in the United States and France) or by precipitation with fuming nitric acid (as in Britain). The current solvent used is "D2EHPA" (di-2-ethylhexylphosphoric acid).

Rare earths such as cerium-144 may also be solvent-extracted (United States, France). In the United States they are separated from one another, e.g. prometheum is separated from europium by ion exchange.
These methods lead to the provision of large and heavily shielded installations, half of which are chemical plants for the fabrication of the actual chemical substance, the other half consisting of cells equipped with remote-handling gear for the fabrication of the sources intended for industrial application.
The plant projected by Hanford for separating 10 million curies of caesium, 10 of strontium, 30 of prometheum and 100 of cerium was estimated in July 1963 at 14 million dollars for the final part, i.e. for the product purification and source fabrication; according to American reports this would make it possible to supply the following:
a curie of strontium-90 at $0.127,
a curie of caesium-137 at $0.102,
a curie of cerium-144 at $0.007,
a curie of prometheum-147 at $0.033.

Possible applications for fission products

The present applications of fission products are only an infinitesimal part of the potential uses of the energy which they release. Let us recapitulate them briefly; first, the use of gamma radiation from caesium-137 for gammagraphy, teletherapy and the laboratory irradiator; the use of beta radiation from strontium-90 for thickness gauges; and the use of prometheum-147 as a source for the excitation of luminescence.
Radiations could come to be used on a very large scale indeed; for instance the irradiation of foodstuffs, if it develops according to forecasts during the coming years, will entail large-scale use of caesium-137.
The second way of applying fission products is the development of the terrestrial or spatial SNAP which seems likely to be capable of absorbing large quantities of fission products in the fairly near future (see Fig. 4).
Fission products may in fact be considered as a particular type of heat source, i.e. as a thermal by-product of nuclear energy.
Assuming that the radiation emitted by the various fission products is totally absorbed and thus transformed into heat, each thermal kilowatt-hour of nuclear origin makes it possible to have available:
26.08×10^{-6} kWhth of caesium-137 in the five following years,
39.72×10^{-6} kWhth of strontium-90 in the five following years,
2.15×10^{-6} Kwhth of prometheum-137 in the two following years,
1.20×10^{-6} kWhth of cerium-144 in the following year.
This thermal energy is at present recoverable by thermoelectric means with a yield of about 5%, making it possible to construct electric generators of low power but with a very long life and a very high stability.
The *Martin Company*, the firm which has carried out most work in this field, has developed meteorological stations, buoys, either luminous via the intermediate stage of electrical energy, or ultrasonic, i.e. by direct conversion of the thermal energy into ultrasonics.
Such applications will be likely to account for a large quantity of fission products, since a 100 We SNAP, for example, consumes 300,000 curies of strontium-90.
Other applications will very probably come to light, such as the already envisaged use of thermal energy released by fission products for water distillation.

Conclusions

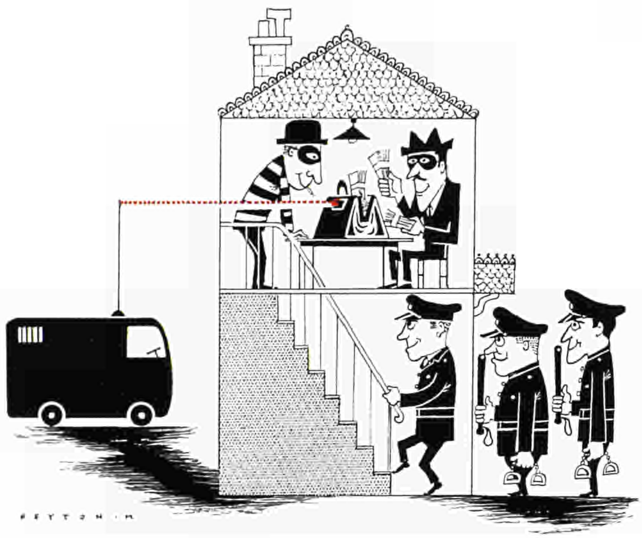
The problem of fission products is a constantly changing one; it is receiving more and more attention owing to the very fact that the steadily increasing number of modern centres means a constant rise in the quantity of fission products in storage. It will therefore be necessary to make progress in this field if the nations are to develop a nuclear energy policy without allowing these stocks to reach dangerous levels. Fortunately the studies carried out on SNAP demonstrate that if fission products can be produced at low cost, which seems possible, a considerable proportion of this by-product of nuclear electricity will be no longer a burden but a marketable product for which novel uses can be devised.
It is clear that a single major application of a fission product suffices to create a considerable demand. It is therefore to this end that the users and producers of fission products are working.

Estimates of French fission products available in the medium-term in millions of curies

	1965	*1970*	*1975*
Strontium-90	0.52	4.4	10.6
Caesium-137	0.6	5	12
Cerium-144	9.8	83	200
Prometheum-147	2.4	20	49

Estimates of US isotope production in millions of curies

	1965	*1971*
Strontium-90	5	10
Caesium-137	3.5	10
Prometheum-147	0.5	30
Cerium-144	3.5	100



. . . other applications will come to light . . .

Recovery of fission products: A few words on the Euratom programme

As Mrs. Laveissière and Mr. Raggenbass have shown, the research carried out on the separation of fission products is two-pronged. It is directed first of all at devising a solution to the problem, which is gradually becoming more acute, of reactor-produced waste. Secondly, it is designed to find a way of using the isotopes which can be extracted from this waste.

Two research contracts are now under way under the programme launched by Euratom in this field—one at the Nuclear Energy Study Centre at Mol *(CEN)* bearing on the development of a general processing method applicable to solutions of various origins, and the other at the Saclay Centre of the French Atomic Energy Commission *(CEA)*, directed more particularly to the recovery of fission products from French reactors.

These two co-ordinated studies made possible the recovery at the pilot stage of caesium-137, and are now directed at the recovery of strontium-90. They have also resulted in the development of new ion exchangers possessing a particularly selective capacity for these two isotopes.

Other research projects will be undertaken in the near future. They will concern the recovery of other radioisotopes such as technetium-99, prometheum-147 and cerium-144, the solution of certain allied problems of a technological character, and lastly the development of new applications for the products separated out, with special reference to intense radioactive sources. It should be noted, however, that the extraction of *stable* isotopes will also be studied. In fact several of these could serve as targets for the production of new radioisotopes.

SERGE GODAR, *Radioisotope Group, Directorate-General for Research and Training, Euratom.*

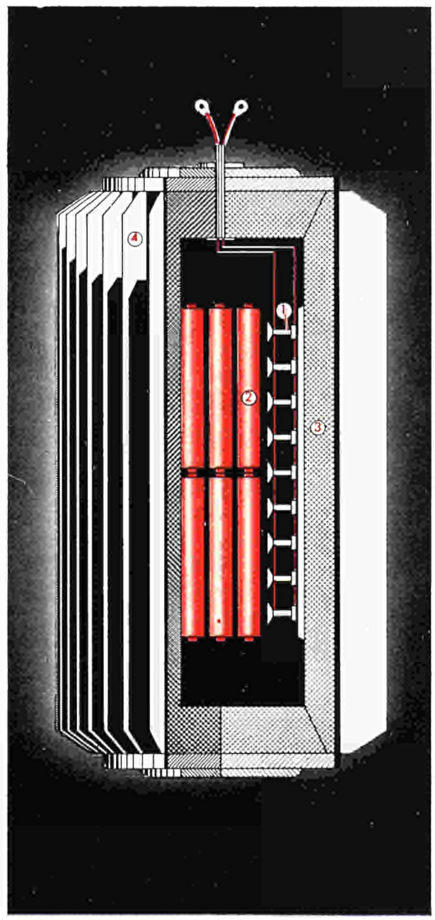


Figure 4: Diagram of a "SNAP", for supplying electric power to a meteorological station. The operating principle of the SNAP is based on the conversion of heat into electricity via thermo-couples (1). These are heated by the cartridges (2) which contain strontium-90 in the particularly stable form of titanate. The purpose of the uranium shield (3) is to absorb the radiation emitted and provide a connection with the cold source, i.e. the environment. Cooling is facilitated by the fins (4).

EUBU 3-23

"Integrated" fuel handling in gas-cooled reactors

HARTWIG BENZLER, *Directorate-General for Industry and Economy, Euratom*

Development to date

One of the major differences in the operation of the two "proven" power reactor systems—the light-water and enriched-fuel system and the gas-graphite and natural uranium system—lies in the method of loading and unloading fuel elements.

Water-cooled reactors must be shut down throughout the fuel-handling procedure, which may take several weeks; the pressure-vessel lid is opened and the various elements can then be withdrawn by means of manipulators. On the other hand, since the loading compartment is under water, cooling the elements and shielding against radiation present little difficulty. The requisite installations and equipment can therefore be relatively simple and robust.

In gas-cooled reactors the situation is reversed: fuel elements can be unloaded while the reactor is in operation, but the handling devices used hitherto seem more complicated. This is particularly true in the case of older plants, where the strangest assortment of machines and equipment are sometimes to be found.

In the more recent gas-cooled reactors there has been an effort to reduce the number of specialised machines and combine as many functions as possible in one master-machine. These handling mechanisms can be of quite considerable size, as will be seen by a glance at Fig. 1, showing the loading machine at the Latina (Italy) power plant. There are several reasons for this:

a. Apart from the actual changing of the fuel elements, these devices must be able to perform a certain number of other operations; they must, for instance, be used for changing the control rods, including the winch mechanism and safety caps, an operation which, in water reactors, is completely independent of the loading system.

b. Fuel elements are changed while the reactor is in operation. It is true that in some of the earlier plants (*Calder Hall* and *EDF 1*) it had been arranged to shut down the reactor during the unloading procedure. Furthermore, in one case, the primary circuit had to be depressurised. Later, however, the system of unloading during operation, already put to the test in the G 2 and G 3 reactors, was developed. It is clear that such a solution presents greater difficulties, but it has indisputable advantages to offer: spent or damaged fuel elements can be changed at any time; the replacement or permutation programme can easily be made to conform with the optimisation requirements of the physics, thermodynamics, technology and economics of the system; finally it is possible, at any time, to change control rods, to add or remove absorbers or to carry out other handling operations inside the reactor pressure vessel.

c. The third basic reason lies in the need to ensure sufficient protection against radiation.

In water-moderated reactors, all handling operations can be performed under a sufficient mass of water to make additional precautions against radiation unnecessary, except that the staff carrying out the operation must be properly stationed.

In gas reactors this simple solution is impossible, for not only must the handling platform be protected by a thick layer of concrete against radiations from the reactor core, but the space all round the loading machine must be provided with thick shielding against radiation from the elements inside. In the same way every device needed for changing the elements has to be shielded properly against radiation. The result is a bulky, inconvenient and costly structure.

All these features of the handling devices used hitherto in gas-cooled reactors—the multiplicity of operations, on-load operation, the anti-radiation shielding—clearly account for the high costs. It should nevertheless be pointed out that, from the technical point of view, gas-reactor loading machines have reached an advanced stage of development. For instance the machines of the G 2/G 3 reactors can unload, without shut-down, up to 40 channels per day and operate habitually at a rate of 27 channels per day (this corresponds to three tons of fuel). The most stringent demands as to precision, adaptability and operating safety can now be met. These handling devices, which sometimes weigh over 500 tons and stand nearly 20 metres high, are real technical masterpieces.

New proposal

In view of the various foregoing circumstances, it was natural to try to improve the handling devices in gas-graphite natural uranium reactors.

In France the organisation responsible for major reactor developments is the CEA (Commission for Atomic Energy). The French nuclear power plant programme, like its British counterpart, lays especial emphasis on reactors of the natural uranium gas-graphite type. Here we have a long string, starting with the Marcoule G 1, G 2 and G 3 reactors, continuing via the four nuclear power plants EDF 1, EDF 2 and EDF 3 at Chinon and EDF 4 at Saint-Laurent-des-Eaux, to proceed at the rate of one 500 MWe plant per year in the next few years.

One of the most interesting results of developing gas-graphite reactors in this way has been the final adoption of prestressed concrete pressure vessels (EDF 3, EDF 4), a technique which had already been used for the G 2 and G 3 reactors. The reasons governing this choice need not be detailed here, but one of them was that there is practically no limit to the internal dimensions of the vessel (which is not the case when steel is used); this enables an ever greater proportion of the total primary circuit to be housed in the pressure vessel. At first this vessel contained only the reactor core (G 2, G 3 and EDF 3), but then new formulae were adopted, in which the steam generator and primary circuits were included in the vessel *(Oldbury, Wylfa, EDF 4)*. The last stage in this development is to *include the handling device as well, thus achieving a fully integrated installation.* From the angle of simplicity of layout and protection against a sudden coolant loss, a reactor of this type would probably be unbeatable. Fig. 2 sketches out the history of this development. It is clear that with increased integration, the overall system gains in simplicity.

Figure 1: Fuel loading and unloading machine of the Latina nuclear power plant (Italy).

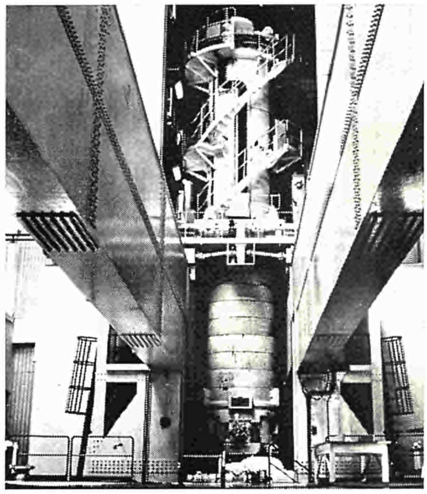


Figure 2: Three stages in the "integration" of gas-graphite reactors

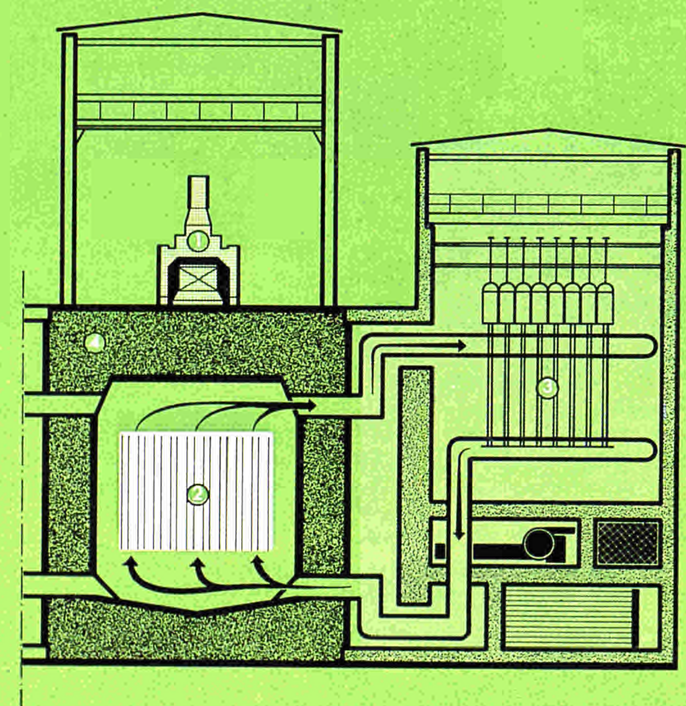


Figure 2 (a): Non-integrated layout.
The vessel only houses the actual core of the reactor. The loading machine and the heat-exchangers are outside the vessel.

1. *Loading and unloading machine*
2. *Reactor core*
3. *Heat-exchangers*
4. *Prestressed concrete vessel*

Hence it is not surprising that the perfecting of fuel-element handling devices occupies a high place in the European Atomic Energy Community's list of subjects for research during the second five-year programme in the field of proven-type gas-cooled reactors. The Community, under a contract concluded with the CEA, is participating in the necessary development work.

The new handling device is based on the following concept. Inside the reactor pressure vessel, above the core, a relatively shallow compartment known in French as the "grenier" or "loft", is divided off by a shielding plate; the pressure in this "loft" is, however, the same as in the rest of the system. The devices required for handling the elements will be housed in this compartment.

Above each channel a hole is bored through the plate, so that the elements can be inserted and withdrawn directly and along a straight course. Normally these holes are closed with plugs, firstly to limit gas exchanges between the reactor itself and the "loft", and secondly, to lessen the radiation intensity in order to reduce indirect activity in the "loft". Perfectly leaktight plugging for these holes is not necessary; it is in fact not even desirable, as there must be ventilation between the two compartments of the vessel.

Fuel elements or other objects that might be needed inside the pressure vessel are put into or taken out of the "loft" through a lock-chamber system.

The idea on which this new process is based is shown diagrammatically in Figs. 3 and 4[1]. Fig. 3 is a horizontal section of the "loft" above the reactor core. A radial arm, moved by a spur-wheel driven by a pinion keyed to a shaft, pivots round the radial axis of the unit. The pinion driving shaft passes through the concrete vessel, so that the driving gear, being located outside, is accessible at all times.

The vertical cross-section shows that the actual loading machine can move radially along the arm. By means of a winch, a grab which grips the head of the various elements can be lowered into the reactor channels. In addition, the loading machine can transport special baskets containing new or used elements and also the shielding plugs. All movements are effected by means of electric motors connected to the mains by cables and winding-drums or rotating contacts.

After a cooling period the baskets containing used elements are removed through one of the two locks shown in Figs. **3** and 4. These locks consist of a horizontal tube, about 2 m in diameter, closed at each end by an autoclave door. The baskets are then lowered by a simple type of hoist into a pool situated alongside the reactor building. The opposite procedure is followed for inserting new cartridges into the reactor core.

The temperature inside the "loft" is kept at about 70°C by a constant flushing of cold CO_2. The pressure is kept slightly higher than that in the reactor itself in order to drive the flushing gas downwards.

The low temperature maintained in the "loft" makes for easier lubrication of the moving mechanical parts and better results

1. Borrowed from *Atompraxis* 9 (1963), No 11/12, p. 1-4; R. Martin: "Un nouveau dispositif de manutention".

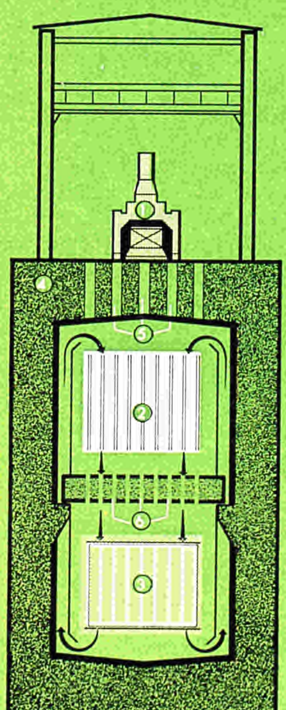


Figure 2 (b): Semi-integrated lay-out
The vessel houses not only the reactor core but the heat-exchangers as well. The loading machine still remains outside the vessel.

1. *Loading and unloading machine*
2. *Reactor core*
3. *Heat-exchangers*
4. *Prestressed concrete vessel*
5. *Loading wells*
6. *Supporting plate*

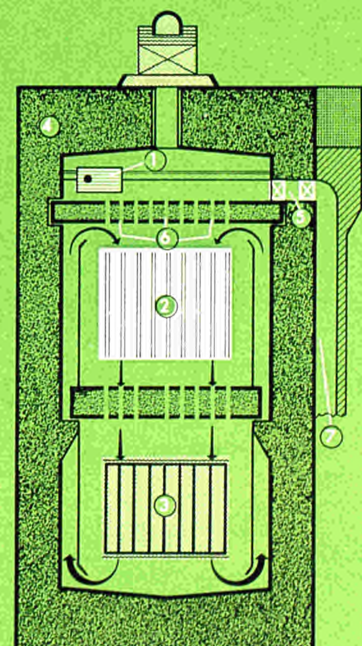


Figure 2 (c): Completely integrated lay-out
The vessel contains all the main parts: reactor core, heat-exchangers and loading equipment.

1. *Loading and unloading machine*
2. *Reactor core*
3. *Heat-exchangers*
4. *Prestressed concrete vessel*
5. *Lock chamber*
6. *Shielding plate*
7. *Elevator connection to cooling pond*

from the electrical equipment, especially cable insulation and contacts.

Advantages of the new device

The new handling device for proven-type gas-graphite reactors has been named "loft-loading/unloading". The value of this invention is enhanced by a number of circumstances inherent in the general trend of development of these reactors.

It is quite conceivable that in the future, fuel-elements with a very large uranium diameter may be used in gas-graphite reactors. This will mean a reduction in the number of reactor channels, with a resultant reduction in the number of holes bored through the loft shielding-plate, so that construction and operation will be simplified considerably.

With EDF 4 the traditional direction for the reactor coolant gas (i.e. from bottom to top) was abandoned in favour of the opposite direction. Apart from the various other advantages this offers, it should be noted, in particular with regard to maintenance, that it gives greater cooling when elements are extracted. Furthermore, the plate separating reactor and "loft" is now only exposed to cold carbon dioxide. Lastly, no special device is required to prevent the fuel-elements from drifting in the gas draught, and this of course simplifies all the loading operations.

The theoretical designing of the integrated system—particularly construction and shielding-plate design—is made easier by the adoption of prestressed concrete pressure vessels, mentioned earlier.

Bearing in mind the simplifications which the general trend of reactor development will bring to the proposed new system, its chief advantages can be listed as follows:

– Since anti-radiation shielding is no longer needed, the mobile parts of the assembly are light and small. Leaktight connections to the pressure vessel are unnecessary, which again simplifies construction. This should bring costs down to a point where standard replacement of the whole device in case of breakdown can be contemplated; this would have the further consequence of saving time and cutting down the equipment needed for repairs.

– Loading takes place along a straight path between the machine and the channel, without the changes of direction or "waiting" stages which loading has always entailed until now. This reduces the risk of jarring or error. Furthermore, there is direct access to the reactor channels from the "loft". Finally, the travel is cut down to the strict minimum; the machine has a simplified programme and also the operations take less time.

– Thanks to the low temperature maintained in the "loft", natural convection should be enough to ensure adequate cooling of the irradiated fuel elements which it houses. This means a further saving on the complicated cooling circuits required by certain of the handling devices so far constructed.

– Instead of the 100 to 200 standpipes, welded to the top of the pressure vessel and passing through the shield to the loading platform, which were needed hitherto, the two locks (one of which serves as a safety and standby access point) are now the only two openings planned for fuel-elements or other parts. The perfectly leaktight locking devices which were hitherto needed when the reactor was operating at full power were expensive and difficult to construct, and it is easy to see the savings which are possible with the new device and the simplification afforded by eliminating the standpipes, which formerly constituted one of the trickiest problems. As the plugs in the "loft" shielding-plate are gravity-operated, they need no leaktight or locking devices.

– Since all the essential parts of the handling devices will normally be inside the reactor vessel, the vast and costly loading and unloading spaces which had to be installed above the biological shield can now be dispensed with, or at any rate substantially reduced.

– By reducing the number of operations required for any handling task and the number of standpipes, reactor safety is increased.

Besides these six main advantages the new handling device offers several others, which we shall pass over here as they are not essential to an explanation of its principle.

A few problems of detail

In general, any new technical development offers not only obvious and profitable advantages, but frequently poses a whole series of new problems also. The integrated loading system is no exception, and some of the more interesting problems are outlined below.

Breakdown service

It has already been said that all moving parts in the "loft" are of simple and robust design; even so, provision must be made to deal with any breakdown, however unlikely.
For serious breakdowns occurring while the reactor is operating at full power, CEA experts have therefore designed a remote-controlled robot which can be introduced into the "loft" and there completely take over the work of any defective motor.
The robot can enter the "loft" by either lock and reach any point by means of a second, fully independent swivel-arm system (see Fig. 3). All mechanical or electrical parts used to drive it are in duplicate for greater safety.
If necessary, the main handling machine can be removed by the breakdown machine and transported to a special repair shop, being passed from one rotating track to the other.
A number of other operations can also be performed without having to shut down the reactor. If several failures occurred simultaneously and the robot could not cope with them, which is highly unlikely, it would still be possible to shut down the reactor, depressurise the circuit and restore a normal atmosphere inside the pressure vessel.
It would then be possible to enter the "loft", after a few days, without special protective measures, and carry out the requisite repairs.

Control

The practice hitherto in gas-graphite reactors has been to use control rods several metres long, which are lowered by winch into the reactor core. With the integrated system this method is no longer practicable, as the two radial arms must be able to move freely. Furthermore, in order to house the control rod lifting devices under the shielding-plate, a considerable space would have to be left free above the core to hold the rods in the raised position, which is not desirable.
It was therefore necessary to find solutions requiring no additional space above the core and allowing of free access to and replacement of all moving parts. It was found that these requirements could be met perfectly in several different ways. Consequently the only factors determining the free space between the top of the core and the bottom of the shielding-plate are the system for ducting gas into the channels and the assembly requirements.

Guiding and supervising handling operations

The whole principle of the loading device drive units inevitably led to the adoption of a marker and guiding system for locating each channel with the aid of polar co-ordinates. The angular position is determined by reference marks cut in the "loft" wall, the machine moving radially along its arm in relation to these marks.
The various handling operations have as far as possible been automated according to prepared plans. For this purpose the plant must be equipped with an absolutely reliable reference-mark system and an electronic guiding device. The main problem, the question of exact positioning, has been solved with the aid of an optical process; the guiding and information processing are electronic.

Lock-chambers

The dimensions of the two "loft" locks depend basically on the size of the mobile loading unit and the emergency machine. Both must be absolutely leakproof against the pressurised reactor gas, a condition

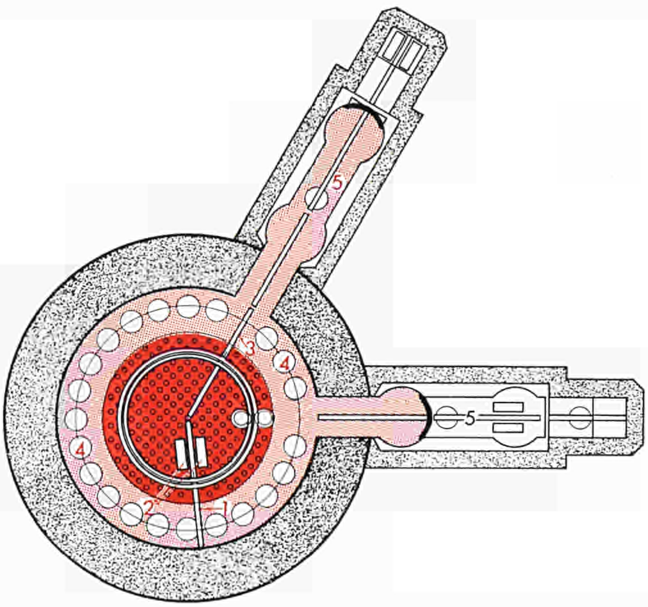


Figure 3: Schematic horizontal cross-section of the "loft" above the reactor core.

1. *Main radial arm*
2. *Loading machine trolley*
3. *Auxiliary radial arm*
4. *Location of baskets for temporary storage of fuel-elements*
5. *Lock-chamber*

made easier by the low temperature obtaining in the "loft" (about 70°C). A feasible solution is to use elastomers applied to the metal base. Light shielding is sufficient to prevent damage by radiation from the used elements. In addition, the possibility of replacement during shutdown has been considered.

Development programme

The object of the testing and development programme launched by the CEA with Euratom support is to study the various novel features of the integrated loading sytem, to develop the design and, on the basis of experiments and practical tests, to create the conditions necessary to enable it to be used in industry.

Full-scale model

At the end of 1962 and the beginning of 1963 a full-scale model was built, at Saclay, on which all the characteristics of the system can be studied and checked under completely realistic conditions, except that there is no pressurised CO_2 atmosphere. A photograph of this model is reproduced in Fig. 5. The loading machine can be seen in the centre, and to its left, fixed to one of the arms, is the breakdown machine with its motor mechanism extended.
Apart from a few minor changes which were found to be necessary during assembly and the first test, this model was ready and put into operation at the end of March as planned, with a temporary master console. The optical positioning system, which fundamentally consists of a set of mirrors inside the "loft" and a television link between the optical signal output and the master console, has been improved at certain points so that a provisional operating test run could be carried out.
Later the mechanical, optical and electronic equipment was further adapted to the desired operating conditions, and commissioning tests of various parts of the plant carried out. By the autumn of 1963 the model was working satisfactorily, so that the temporary console was replaced by a semi-automatic one.
Tests were later carried out for a considerable number of normal and exceptional handling operations, which provided opportunities for trying out the capacities of the breakdown machine. The prescribed operations for loading and unloading the channels, introducing and removing the baskets via the lock-chambers, and a series of emergency operations following simulated breakdowns, were tested a sufficient number of times.
This test programme yielded such satisfactory results that by spring 1964 it was possible to start converting the model for operation with a fully automatic control system.
Fig. 6 shows the loading machine suspended from the guide rails, as seen from the lock chamber.

Basic tests on the behaviour of the plant under pressure and at normal operating temperature

Independently of the prototype tests described above, several basic questions raised by the presence of CO_2 in the actual "loft" (pressure 40 atm. and temperature 70°C) had to be examined.

Optical behaviour of CO_2

It is a fact that differences of temperature in gases can disturb the transmission of images. For this reason tests were carried out in a CO_2 atmosphere on a testbench of the same length as the effective travel of the images in the "loft" (about 9.5 m); these tests showed that in the case of CO_2 the effect mentioned could not be considered as negligible. Theoretical calculations confirmed the experimental results.

Behaviour of electric cables in CO_2 atmosphere

These tests were intended to simulate the stresses the cables undergo as a result of frequent winding and unwinding; they were carried out with a quality of cable which has

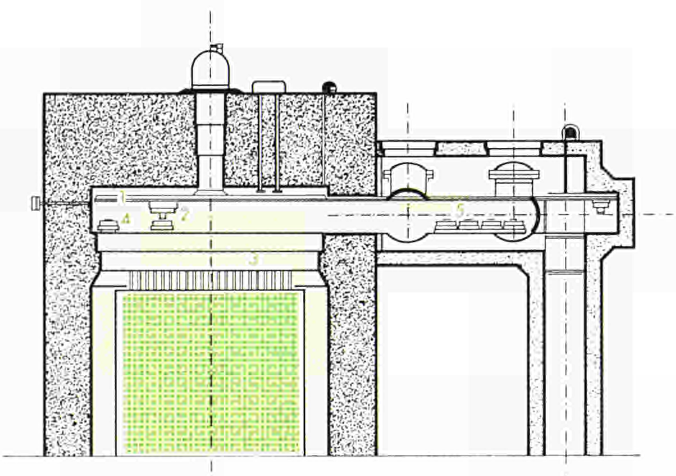


Figure 4: Schematic vertical cross-section of the "loft" above the reactor core.

1. *Main radial arm*
2. *Loading machine trolley*
3. *Shielding plate*
4. *.Basket*
5. *Lock-chamber*
6. *Elevator*

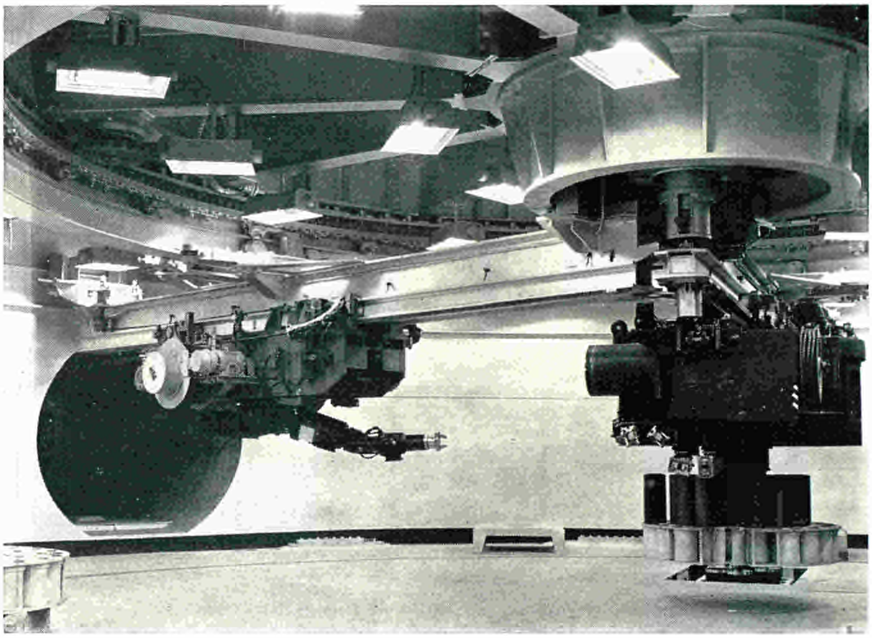


Figure 5: Model of the "loft" handling device; inside of the "loft": on the right, the loading machine, on the left, the breakdown machine.

Figure 6: Model of the "loft" handling device; inside of the "loft" seen from a lock-chamber; in the foreground, the loading machine; in the background, right, the breakdown machine.

already sufficiently demonstrated its resistance to radiations in practice. Information available on ordinary cables was already sufficiently encouraging to justify laying down certain manufacturing principles, especially with regard to the shaping of the cable ends. When the special cables are delivered tests will be continued.

Tests on electric contacts in CO_2 atmosphere

Tests on commutator brushes carried out under varied voltage and amperage conditions showed that even when the current is switched on and off frequently there is no reason to expect any trouble in the CO_2 atmosphere.

Lock-chamber design

Practical construction of the first draft designs proved that adequate solutions can be found; in particular, it is possible to meet all the safety requirements. Efforts are now being made to reduce the dimensions of the leaktight doors as far as possible, in order to attain an optimum design as regards both costs and construction. Moreover, experience with the model so far indicates that both the handling machine and the breakdown machine could be built more compactly without loss of power. So it seems possible from this standpoint, too, to cut down the size of the locks and substantially reduce the bulkiness evident in Figs. 3 and 4.

Various tests were carried out with leaktight gaskets made of different materials; from these tests, which gave positive results, a suitable material was found.

Control devices and motors

During a preliminary study, a number of possible alternatives for the control and safety mechanisms were designed and compared. It emerged that in preference to the traditional rods used for controlling reactivity, it was desirable to adopt a system using boron steel chains, the hoisting mechanism and the housing being located in the "loft" wall.

In the spring of 1964 a contract was awarded to a construction firm to make a detailed study of these control mechanisms and to develop a prototype and the requisite experimental plant for tests. Under this contract the constructor is also to carry out all the preliminary and partial tests, construct the prototype and a testbench simulating effective reactor operating conditions (but without radiation emissions) and carry out creep tests in a CO_2 atmosphere under the prescribed pressure and temperature conditions.

Preliminary testing of the safety mechanisms led to two different solutions, but both, like the control units, depend on the principle of absorbent boron steel chains. The fitting, replacing or emergency servicing of the control and safety mechanisms can be carried out from the "loft" with the handling machine or the breakdown machine.

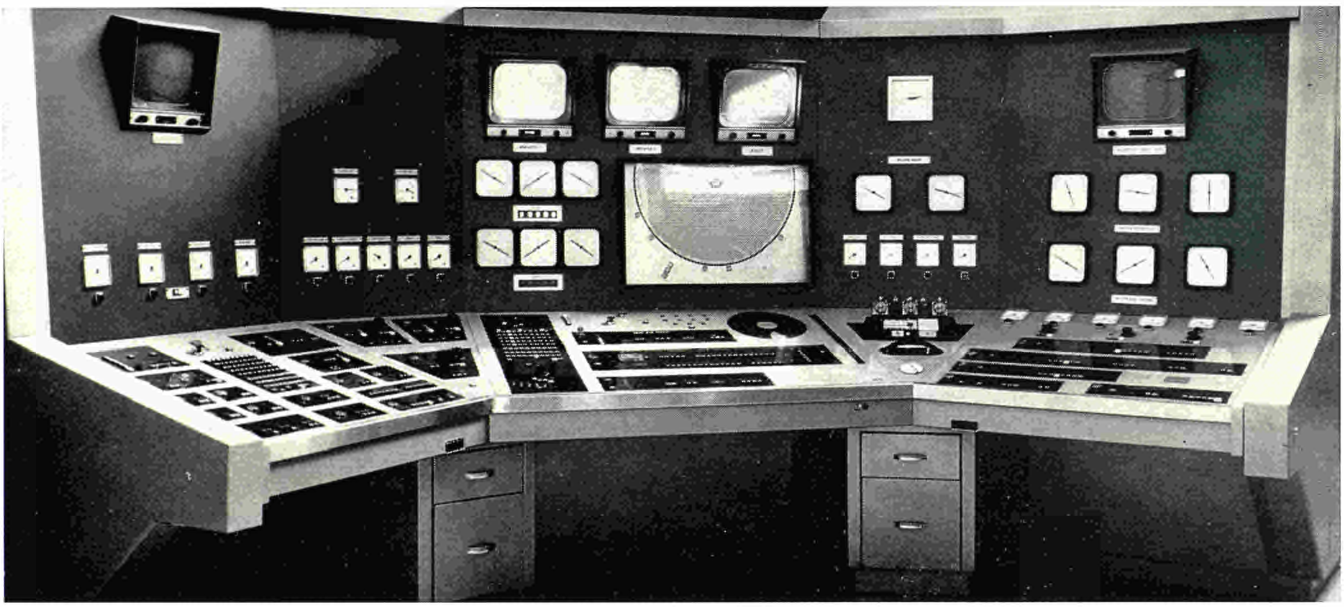


Figure 7: Automatic control console of the model of the "loft" handling device.

Automation of the model

During an initial period, a semi-automatic system was developed by which the various operations could be effected in the form of operational sequences. The operator has to preselect the process required and the co-ordinates of the channel concerned. The sequence then takes place, being repeated by pilot lights which light up on the control panel. After each phase, however, the loading process has to be restarted manually. Various locking and safety devices exclude the possibility of handling errors. A special panel in the control console is used for controlling the breakdown machine. These breakdown operations, which are only needed in exceptional cases, are carried out by special staff. By shunting the normal circuit-breakers it is possible to perform any operation considered necessary.

At the present time the plant is being modified for completely automatic operation, which will allow of day and night testing, according to a pre-selected programme, without any intervention by an operator. Fig. 7 shows the control console as it was in the spring of 1964.

Other research

So far we have mentioned only a certain number of the development projects undertaken under the CEA-Euratom contract. Other important studies are planned or have already been started, in order to round off all the research needed to perfect the new integrated handling system. As these studies are still more or less incomplete, it would be premature to give details of them here.

Conclusions

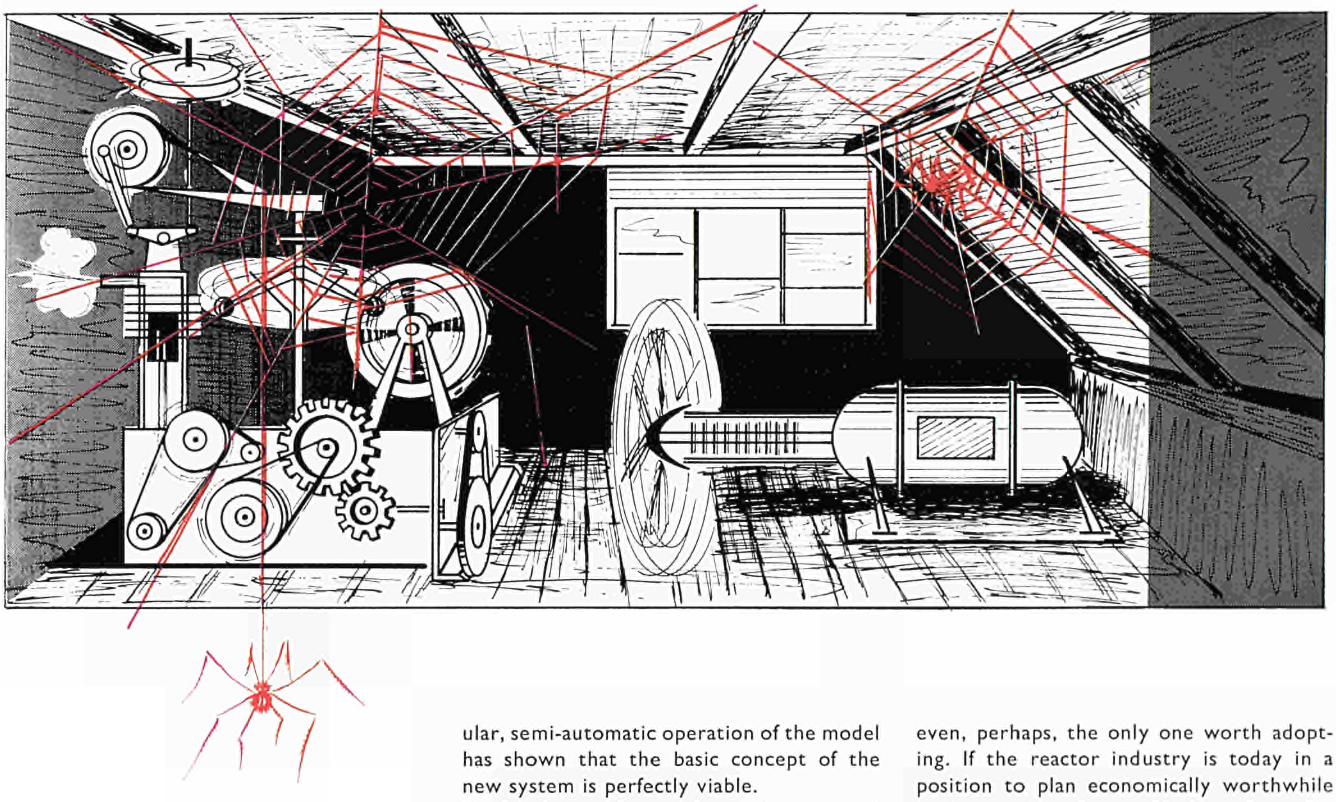
The development work on the new integrated handling device undertaken by the CEA with Euratom's support is not completed yet and it is therefore too early to estimate its ultimate value. Results to date, however, are highly encouraging. In particular, semi-automatic operation of the model has shown that the basic concept of the new system is perfectly viable.

Further interesting results can be expected when the handling and breakdown machine designs are reviewed in the light of acquired experience, and also from the lock-chamber development work. Information of great value will also be yielded by the studies of the position-indicating, programming, automation and guiding equipment.

In view of the great amount of research envisaged and the considerable time needed to develop and thoroughly check all the components in the new device, it was clear from the outset that long-term collaboration with Euratom would have to be sought. The Euratom/CEA research contract therefore covers a period up to the end of 1965. By then a much clearer verdict on the value of the project is to be expected.

Nevertheless, it can already be stated that the chosen formula of systematically perfecting a few types of proven reactors—a line of policy which can be clearly traced in the natural uranium gas-graphite reactor string—has already, in spite of the scepticism expressed in certain quarters, demonstrated that it is perfectly feasible and even, perhaps, the only one worth adopting. If the reactor industry is today in a position to plan economically worthwhile nuclear power plants, this is perhaps due less to revolutionary reactor designs than to the steady, continuous development of familiar techniques.

The new fuel-element handling device for proven-type gas reactors described here comes under that heading. It is a milestone, a step forward whose consequences can be foreseen and which promise to be of the greatest importance in the evolution of atomic energy.



EUBU 3-24

Information and the management

RUDOLF BREE, *Director of the Centre for Information and Documentation, Euratom*

Technical and scientific activities throughout the world are constantly increasing and the various fields in which they are deployed are overlapping more and more. As a result, anyone wanting to make a serious attempt to keep track of these activities finds himself before a kind of immense bubble-chamber in which a growing number of publications plays the role of the tell-tale bubbles lying along their criss-cross paths. It is virtually hopeless to attempt to give an accurate figure, but it can be safely assumed that, at the time of writing, over a million scientific publications—books, articles, reports—are being turned out annually.

Even if we limit ourselves to nuclear science and technology, the probability is that well over 10,000 projects are now being worked on simultaneously in various parts of the world. The number of scientists engaged on them is several times the number of the projects themselves. Between them, they are publishing works today at the rate of more than 50,000 per year; this sector, with its many different subdivisions, is thus seen to be an extremely active one.

No one person can read everything that has been published in the field of nuclear energy over the past year. In any case he should, on top of this, have some idea of what has been published in previous years. No doubt much of this can be regarded as out of date—or that, at least, may be the opinion at a particular time. But how often has this opinion been expressed, and how often have old results had to be re-examined because in the light of new data they took on a new importance?

Most of the research projects under way today require vast sums of money. Some of them follow parallel courses, and while this duplication may be deliberate in some cases, in others it may be fortuitous and stem quite simply from a lack of co-ordination.

In view of the enormous sums involved, the obvious thing to do before tackling a particular project would surely be to obtain detailed information on the data already available on the subject, to ascertain what comparable work has been performed, what served as a basis for it, which solutions proved to be useful, and which less favourable or even impracticable.

Information retrieval—a specialised task

If careful investigations of this nature are undertaken far less frequently than they ought to, the very vastness of the amount of literature from which information has to be drawn is certainly to blame. The retrieval of the relevant literature is a task in itself, the difficulty of which sometimes acts as a deterrent, and which calls for highly specialised knowledge. Who knows all the sources which should be checked? Who knows how they can best and most quickly be turned to account? One will certainly be prepared to check material, but willingness to shoulder also the burden of looking for it oneself is usually much less marked. It can therefore happen that the use of information already obtained is dispensed with, either in order to "save time" or for some other reason.

Speed with accuracy

The consequences of this omission are seldom discovered early enough; worse still, the omission itself is not always discovered. With an annual growth rate of at least 50,000 relevant nuclear documents, as stated above, it is undoubtedly becoming more and more difficult to check information thoroughly; it is in fact possible only if the process is simplified considerably, i.e. if it can be carried out fast enough without sacrificing reliability.

In the case of large and rapidly growing collections of documents, this task is so difficult that it can no longer be solved by ordinary manual means. On the other hand electronic computers can be of use here, even though they were hitherto designed almost exclusively for performing complex calculations. Their "memories" can be extended by adding extra storage capacity in the form of magnetic tapes. While computers are thus extremely helpful by accelerating the processing of information, they should nevertheless not be considered as a panacea for the solution of *all* documentation problems.

It is not enough to store away information; the data on each individual document concerned must also be recorded with the utmost clarity and as skilfully as possible, so that it can be found again if a particular request is made. This means that the contents of the document must be analysed, which in turn can only be done by someone who possesses enough specialised knowledge to understand the document. There is accordingly a need for trained scientists who at the same time have some compre-

of research

hension of the possibilities offered by mechanical information processing.
There are no existing examples in Europe for the use of computers for information retrieval which can merely be imitated. It is only in the US and USSR that systems of this type have been worked; in Europe the necessary financial backing has hitherto not been available and the number of potential "customers" in each country, relatively small when considered from a purely national standpoint, has not warranted the heavy outlay involved.

Creating an information storage unit

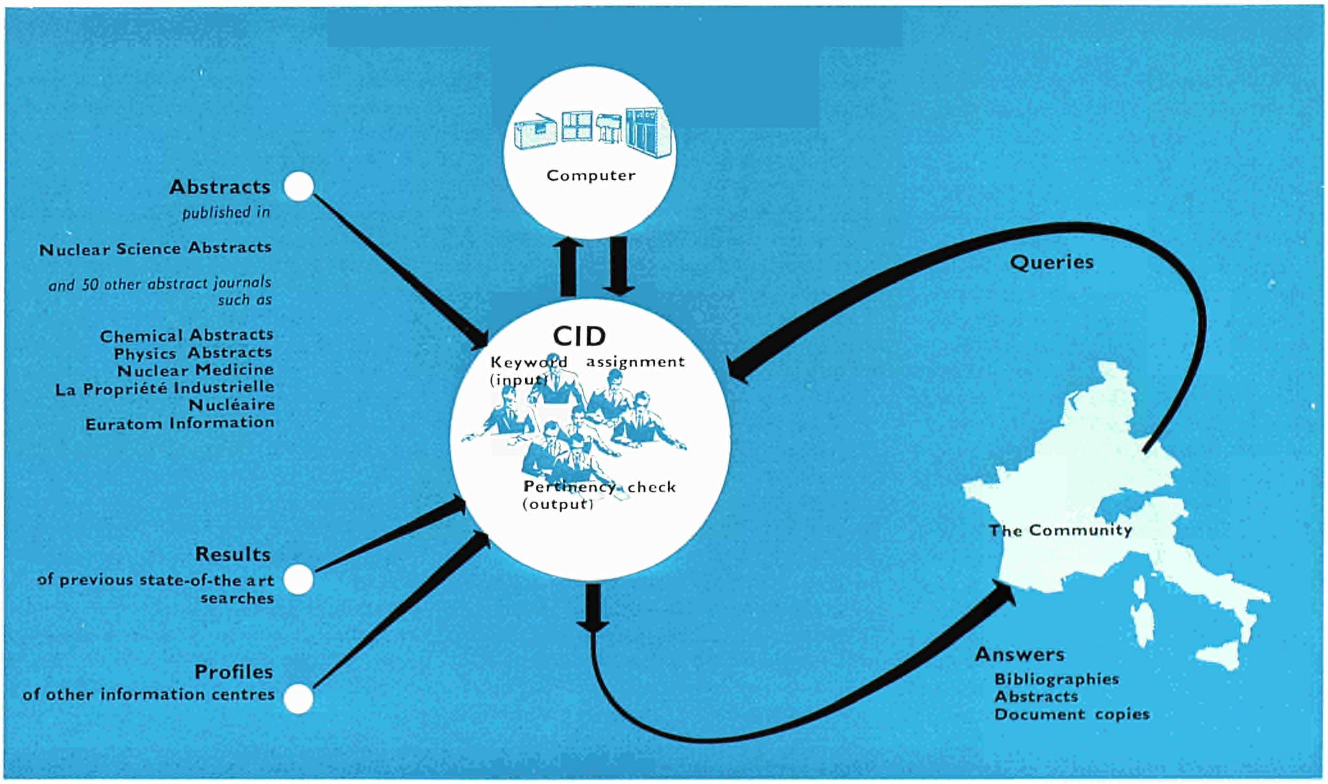
However, the creation of the European Atomic Energy Community provided a justifiable basis for the setting up of an information storage unit, by reason of the large number of interested parties and the possibility of spreading costs. Accordingly, preliminary steps were taken in 1961: a keyword system (see Euratom Report 500 e, *Euratom Thesaurus*) was first developed, based on statistical investigations, and a start was made with the working-out of machine programmes and the actual indexing of documents by assignment of keywords. If it is borne in mind that so far, up to mid-1964, keywords have been assigned to about 200,000 documents, some idea is gained of the scope of the project.

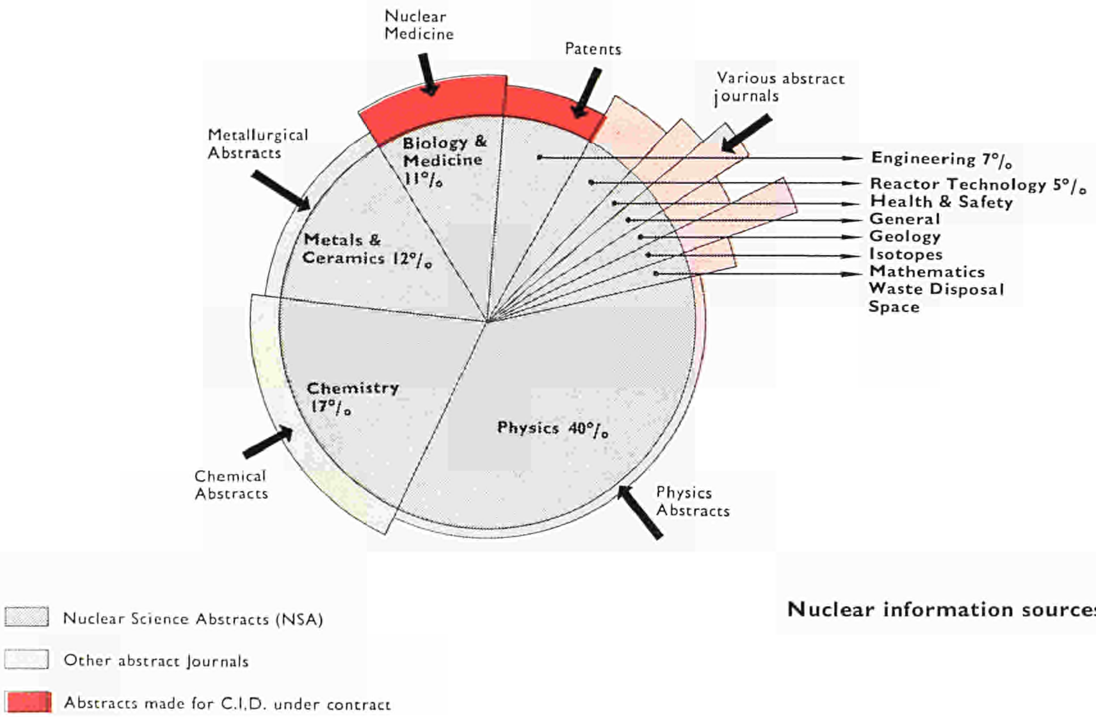
As for new documents, the number of which is increasing from year to year, their preparation for storage will be carried out in close collaboration with the *United States Atomic Energy Commission (USAEC)*, which is taking a lively interest in the project and is seriously considering participation in it on a permanent basis.
In this way the close co-operation between Euratom and the USAEC would also encompass technical and scientific documentation—a field to the development of which the United States have already made an essential contribution by the creation of the exemplary *Nuclear Science Abstracts*.

The storage unit and its basic purpose

The original idea behind this information storage unit was to improve access to "relevant" literature, and in particular to speed it up. Before it goes into operation —planned for 1965—, it is also essential that a careful check should be carried out on the entire procedure used, which was developed

Documentation - the electronic way





Nuclear information sources available to Euratom

in close collaboration with the *CETIS (European Scientific Data Processing Centre)* Research Group at the Ispra Research Establishment and may possibly have to be modified in the light of the experience gained.

What is demanded of the system in its present form? A research worker, a commercial firm or a study group, say, describes in plain language and as exhaustively as possible the problem for the solution or clarification of which all the relevant literature is required. This may be a single request or, on the other hand, the "client" may wish to be kept informed at regular intervals of all new documents referring to the problem concerned.

These requests are analysed in Euratom's *Information and Documentation Centre* and converted into "questions" to be posed to the storage unit. With the aid of the current "storage programme", these questions are answered in such a way that all the literature sources bearing on the question can be retrieved with the utmost celerity and reproduced in the form of a list of bibliographical references. If desired, limitations can be made with regard to the age of the documents: for instance, one can ask for "all documents referring to the problem which have appeared *since 1963*".

The value of the list obtained depends both on the quality of the original keyword assignment and on the skill and intelligence used in converting the problem posed into "machine language". The Centre has set itself the aim of obtaining as high a percentage of the existing relevant documents in as short a time as possible. Perfect, i.e. 100% correct machine answers are not expected here, particularly in the initial stages; it is hoped rather that the answers will be of sufficient quality to make it easy for the specialists of the Centre, by putting further slightly different questions or by carrying out complementary manual searches, to obtain comprehensive results very rapidly.

The client submitting a request receives as his answer a list of bibliographical references, which can be supplemented, if necessary, by a set of file cards containing the corresponding abstracts; abstracts, since they afford more information than the title, can better help the user to decide which documents he requires in their entirety. Help in obtaining complete texts can also be given to the user, provided they are so-called "research reports", which, as opposed to articles published in periodicals, are not subject to copyright laws. The Centre's library is at present systematically collecting all research reports whose data have been included in the information storage unit, and copies can be supplied on request.

Further possibilities

We have just dealt with the "basic purpose" of the storage unit now being formed, namely, the supply once only, or regularly, of data in reply to a given question. Although no start can be made on the implementation of this fairly conventional purpose until the end of 1965 owing to the mass of material to be processed, Euratom is now engaged on investigating other hitherto little explored possibilities offered by the use of the new instrument.

Many information centres, for instance, are systematically compiling the manuscripts of bibliographies on acute problems, minor aspects of nuclear technology, etc., which, if purely manual methods are used, involve many months of preliminary work and finally an often complicated printing procedure. There can be scarcely any doubt that it should be possible, with the aid of the information storage unit, to compile even copious bibliographies much faster and, after a critical check, to classify them with the help of the machine, even in great detail, according to main contents in virtually any desired order. After this the entire text of the bibliographies could be printed out by the machine in a form suitable for reproduction, and this without any proof-reading being necessary. The quality of the results thus obtained would be materially affected by the completeness of the appropriate data in the storage unit and also by the skill with which the information specialists are able to utilise its possibilities.

Putting information at the service of management

There is yet another field in which a major service can be provided through the medium of an efficient information storage unit. The development and exploitation of nuclear technology are given financial support, sometimes considerable, by the Community countries either directly or via Euratom.

The decision in favour of a given project would undoubtedly be greatly facilitated if it became standard practice to provide the authorities not only with details of the project but also with a carefully compiled report on the present "state of the art" in the field covered by the project. In other words, a critical assessment of all the published results of previous work relating to the project should be demanded.

It might even be felt that such projects should as a matter of course take this "state of the art" as a basis. Recent British investigations have shown, however, that this is much less frequently the case than might be thought[1], and it is practically certain that these findings apply to other countries as well. Why is this? The British studies provide no clear-cut answer to the question, but one of the reasons for this inadequate use of already acquired knowledge is doubtless the considerable trouble involved in pinpointing the relevant literature, to say nothing of obtaining it and examining it once it has been identified. But the possible drawbacks of this neglect can be appreciable, in the sense that a great deal of time is wasted and public funds to boot.

It should, then, be obvious that an efficient information storage unit staffed by a capable team of specialists would provide an excellent means of gathering rapidly the results of previous work. The critical processing of the retrieved literature is then, of course, the task of, and only of, those responsible for handling the project. While it takes trouble and time, the costs involved account for only a very small fraction of the funds needed for the project as a whole.

To judge by the British findings, such a method, involving relatively small expenditure, should ultimately help to make the large sums of money invested more secure. But the existence of a fast and efficient information storage unit is a condition for the implementation of such a measure, because the retrieval of the requisite data is thereby decisively accelerated.

It emerges from these conclusions that information deserves a certain standing not only as an instrument of scientific and technical progress in the laboratory. Surely it can become a useful tool as well for the top-level managers and decision-makers. This will become even clearer if our argument is pushed one step further.

Is there not some way of verifying whether this method, developed for analysing technical and scientific literature, could not be used for analysing, describing and comparing the technical and scientific substance of research and development projects? Or, in other words, it would seem that the keywords and their combinations developed for revealing the contents of technical literature, are also suitable for describing the technical contents of research projects. If this could be corroborated by appropriate studies, it would doubtless mean that a way had been found to encode entire research programmes in detail, thus enabling them to be classified and made comparable. This would be an appreciable contribution to something which is constantly being demanded with varying degrees of vociferousness: co-ordination of the technical and scientific programmes of the Member States with one another and with the Euratom programme. In this way, the entire technical and scientific potential of the European Atomic Energy Community could be put on a far more rational basis by avoiding both unnecessary duplication of effort and inadequate exploration of certain fields—which means, in short, that public money could be put to better use.

The creation of such an instrument would be of considerable significance to Euratom since hundreds, or even thousands, of such technical projects could thereby be compared, Euratom being committed to furthering this co-ordination by the terms of the Treaty of Rome.

All this may be a pipe-dream, perhaps, but it is the logical development of the creation of an instrument, the primary purpose of which is to clear the entangled tropical jungle of scientific and technical information. An attempt to solve this problem along up-to-date lines would entail moving beyond the accepted European concepts of the use of information. It is worth noting that they would accord with the recommendations put forward by an American scientific commission which was asked by the late President Kennedy to conduct an enquiry into the relationship between the world of science, government and scientific and technical information.[2]

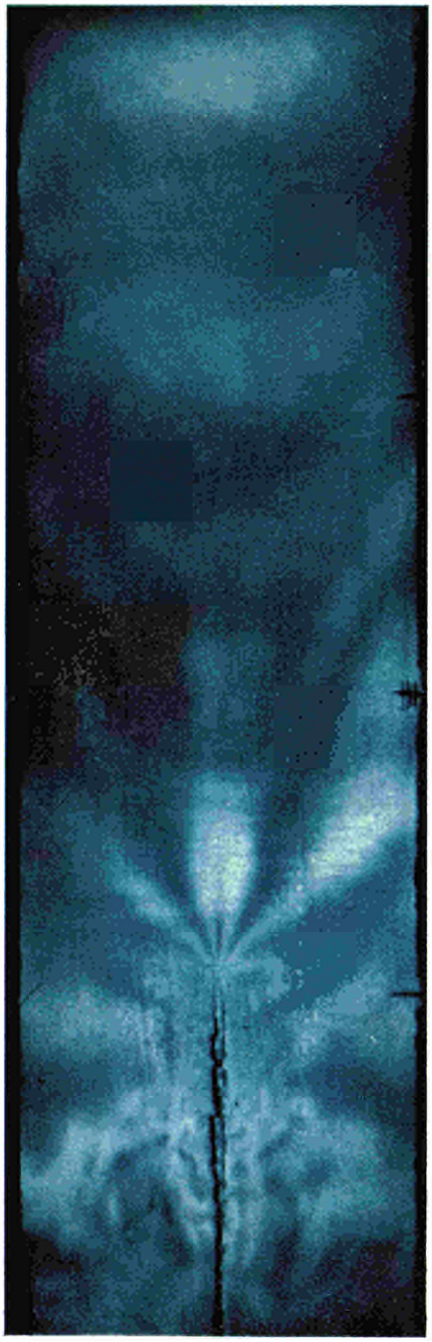
Strong science and technology means prosperity; good management makes for strong science and technology; good information is a prerequisite for good management.

1. Report of an investigation on literature searching by research scientists, by John Martin, Aslib Research Department, 1964.

2. "Science, Government and Information"—The Responsibilities of the Technical Community and the Government in the Transfer of Information—A Report of the President's Science Advisory Committee.

EURATOM NEWS

Configuration of a dynamic stress field near the leading tip of a "brittle" crack propagating in a steel plate (T.N.O., Delft).



Progress in counteracting brittle fracture in welded steels

During the Annual Meeting of the International Institute of Welding, which was held at Prague in July, several papers were submitted by researchers working under contracts concluded by Euratom with bodies in the Community. The research projects covered by these papers form part of the "Steels" programme, an important sector of the United States/Euratom Joint Programme aimed at the development of light-water reactors.

Prominence is given to steels in this programme in view of their importance among the materials used in the construction of pressure vessels and primary circuits for these reactors. Since it is quite out of the question to build complex components of this type in one piece, recourse must be had to welding for the purpose. Now it is known that large welded assemblies, by reason of their vast size, give rise to problems which have not yet been completely solved.

While engineers no longer have any apprehensions concerning the behaviour of these components in normal operating conditions, they are still uneasy about their ability to withstand unusual stresses such as an impact, or even a sudden temperature surge as would occur in the event of a scram shutdown.

It is what has been designated "brittle" fracture that arouses the most anxiety in such conditions. This phenomenon forced itself sharply on the attention of the experts when, more than twenty years ago, a series of accidents occurred, some of which proved catastrophic. Ships the design of which seemed to have embodied adequate safety factors split in two during a voyage in cold seas; steel bridges collapsed, often in the dead of winter, through the action of internal stresses.

Thus the fact had to be faced that steel which at normal temperatures of around 15°C had passed with flying colours the conventional tests applied by metallurgical laboratories did not, at appreciably lower temperatures, possess the resistance properties expected of them. It became necessary to employ the term "transition temperature", above which the well-known "ductile" fracture phenomenon might occur subject to a fairly considerable deformation stress, and below which the steel might sustain a "brittle" fracture as a result of even a very slight impact.

Depending on the alloy, on the treatment to which it has been subjected, and on certain characteristics of the medium, such as the presence of a neutron flux, this transition temperature may attain a fairly high value. It is therefore impossible to discount a brittle fracture in the case of light-water reactors on the pretext that they will never be exposed to arctic temperatures.

One of the pre-requisites for the triggering-off of a brittle fracture in a welded assembly is the existence of a sufficient degree of internal stresses. Now it has been established that an automatic welding process known as *Electroslag* only engenders relatively small internal stresses. Through one of the research projects carried out by Euratom under contract and reported on at Prague, it has been possible to study the parameters governing the distribution and the intensity of the residual stresses in heavy-gauge joints welded by this process. Henceforth, the *Electroslag* process makes it possible to regard the welding of very thick pressurised components with a far greater degree of optimism.

An international conference on biomedical methods of preparing and using labelled compounds

Euratom and the Universities of Rome, Bologna and Padua organised an international Conference at Venice, from 24 to 29 August 1964, on biomedical methods of preparing and using labelled compounds.
This important event was a sequel to the first, Euratom-sponsored, International Conference on methods of preparing and storing labelled compounds, which took place in Brussels from 13 to 16 November 1963.
On that occasion it was arranged that special aspects of the questions reviewed at the time by some 180 international experts would be dealt with at a later date. The Venice Conference forms a part of this scheme and shows once again that the Community programme on labelled compounds is carried out in close co-operation with the Member States and, in particular, with the specialist university bodies in the Six countries. In the main, the questions discussed in Venice centred on three principal themes:

1. *The study of the effects of new drugs:* For too long the testing of any new drug has concentrated on its primary effects. Certain accidents (which led to notorious lawsuits) threw a harsh light on the importance of a drug's secondary effects, notably in the case of prescriptions for pregnant women. The secondary effects of pharmaceutical preparations can, in fact, be easily detected by "labelling" and studying the distribution of the labelled drug or its decay products throughout a living organism.

2. *Metabolism studies:* further research into still unexplained basic processes in living beings. This leads on naturally to chemical applications and to the perfecting of new therapeutic methods; thus, by studying the metabolism of cancerous tissues, or of maladies such as anaemia, with the help of labelled compounds, effective curative methods have been found for these diseases.

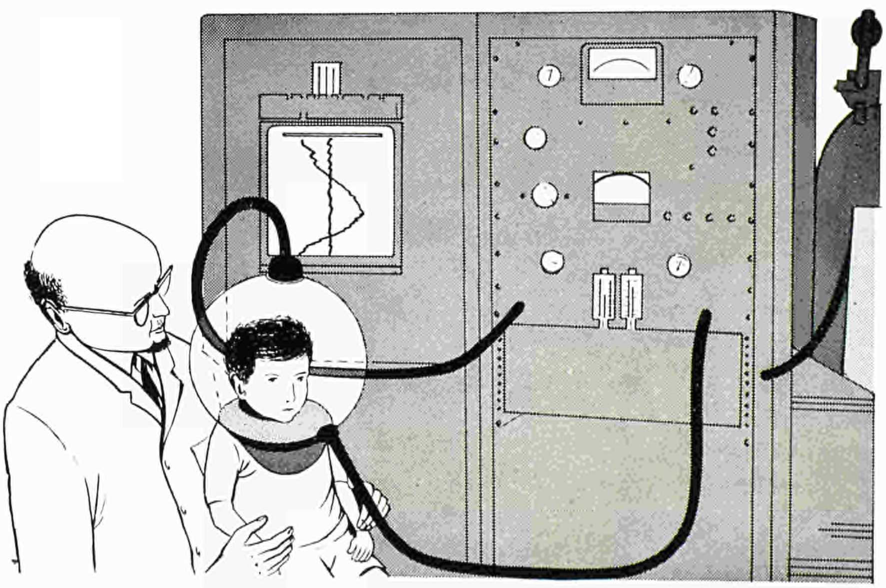
3. *Instruments:* this mainly concerns instruments using labelled compounds for purposes of diagnosis. Two types of instrument in particular were described in Venice:
a) equipment giving respiration diagrams using ^{14}C-labelled CO_2;
b) equipment for measuring tritium and carbon-14 in the blood.

Setting up of a laboratory of nuclear medicine

On 2 October 1964 the medical clinics of the Free University of Brussels inaugurated their *Central Nuclear Medicine Laboratory*, set up under a contract of association with Euratom and the University of Pisa (Italy).
The current research programme covers the use of nuclear methods in the diagnosis and treatment of diabetes, thyroid and heart diseases, infant malnutrition, kidney and blood diseases and cancerous tumours.

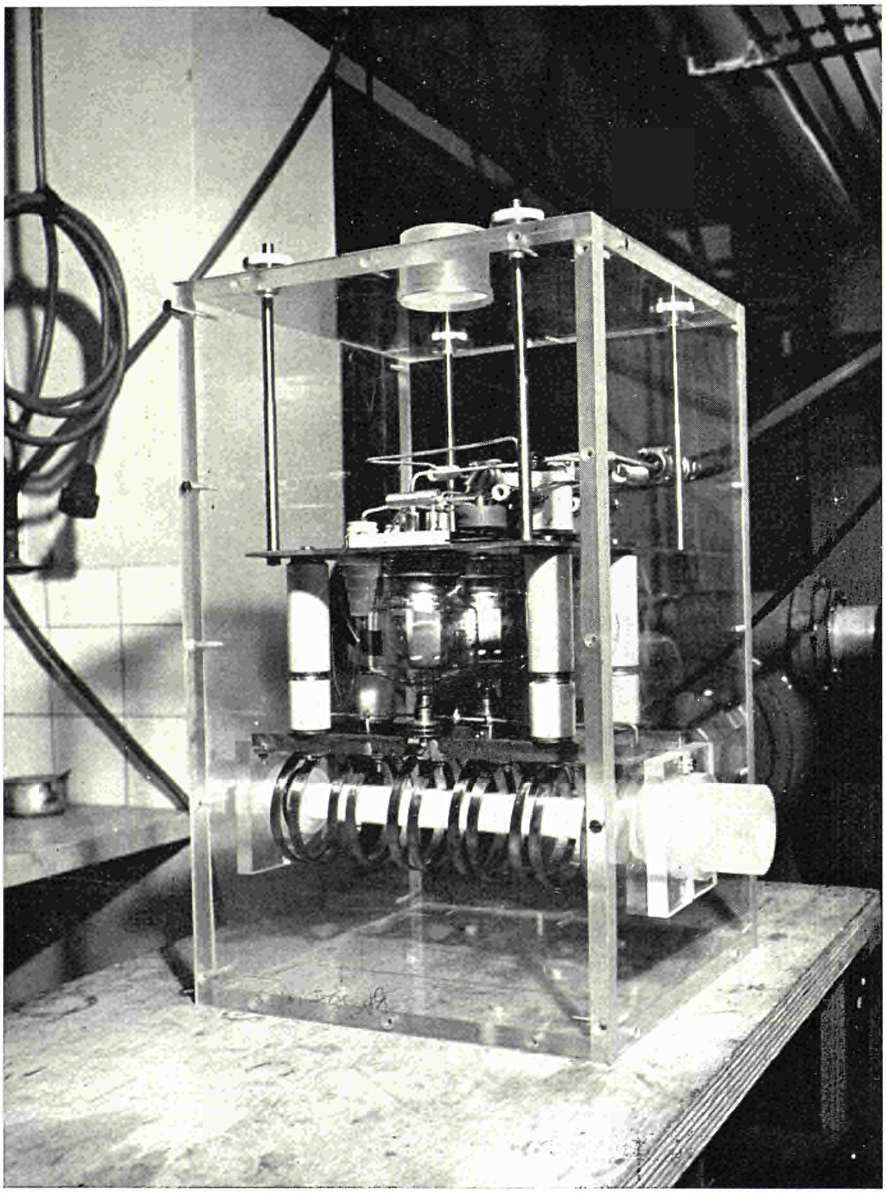
Marked molecules in medical diagnosis

By means of the device illustrated in the figure, it is possible to determine the way in which the organism uses a given organic substance. The substance, marked in one or more of its carbon atoms, is administered to the subject, after which the radioactivity of the CO_2 exhaled by the lungs is recorded. In this way, a curve is obtained which, if it deviates from the normal pattern, may yield accurate information on the nature of the ailment from which the subject is suffering, e.g. defective functioning of an organ. Electronic computers must be used to analyse the curves thus obtained.
Is automated diagnosis just around the corner?



EURATOM NEWS

Experiment on interferometric measurements of electron density in a plasma (Frascati, Italy)



Conference on technical problems in thermonuclear research

Research on controlled thermonuclear fusion could not be carried on without a whole range of high performance equipment, much of which cannot be obtained on the normal market and has to be constructed in line with the most exacting specifications.

In order to review the latest technical developments in this field, 130 representatives from European and American controlled thermonuclear fusion laboratories and a number of specialist firms attended the Third Conference of Technical Problems in Thermonuclear Research, held in Munich on 22-26 June 1964. Thirty-six percent of the papers were contributed by representatives of laboratories working under contracts of association with Euratom.

It will be recalled that the object is to confine a "plasma" of atoms of light elements, in particular deuterium or tritium atoms, so as to bring about the fusion of their nuclei. This involves creating a vacuum in the space in which the experiment is to take place, placing the "fuel" in the vacuum and heating it up to several million degrees, confining it by means of magnetic fields to trigger off the fusion process, finally observing the course of the experiment for the lessons to be drawn from it.

Thus these experiments demand tremendous sources of electric energy, machines able to store vast quantities of that energy and then discharge it in a fraction of a second, switching devices capable of controlling such discharges, apparatus to set up the magnetic fields and create the vacuum, and instruments capable of giving the researchers accurate information on the results of their experiments.

The conference showed that real progress is being made in techniques. For instance, there already exist several capacitor banks of over 1 megajoule, i.e. capable of

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discharging more than 10 megawatts in one-tenth of a second.

A number of laboratories have been working on superconducting coils and several specimens have already been produced; although there is still a great deal to be done, their use in various forms offers good prospects. Their main value lies in the fact that with such coils it is possible to install circuits which could attain zero resistance and in which a current once induced would be self-sustaining.

Another advance is that vacuums of 10^{-10} mm Hg can now be obtained in appreciable volumes, whereas only a few years ago anything beyond 10^{-3} mm was impossible.

A single example will suffice to illustrate the progress achieved in the "diagnosis" facilities which make it possible to study fusion phenomena—clear photographs have been obtained after exposures of less than a hundred millionth of a second.

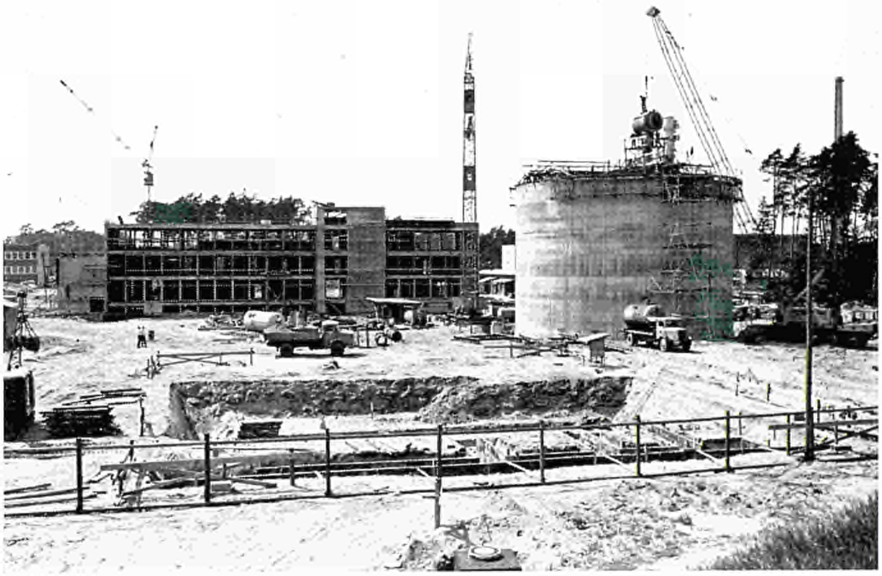
Enlarged co-operation between the United States and Euratom on nuclear documentation

The Italian town of Stresa, which is situated near Euratom's Joint Nuclear Research Centre establishment at Ispra, was the scene of an international conference on nuclear documentation organised by the USAEC in collaboration with Euratom from 14 through 16 September 1964. Nearly 70 experts from the US, the European Community, some 20 other countries and various international organisations attended in order to study the range of problems raised by nuclear documentation.

The American representatives were thus enabled to define their present policy, which consists in bringing about a greater measure of centralisation (to obviate duplication of effort) as well as achieving a better standardisation of the format of scientific reports (mainly by adopting a single type of microcard).

The intimate co-operation already established between Euratom and the United States in this field will soon be given a fresh impetus, in view of the fact that Euratom's Information and Documentation Centre (CID) and the USAEC are planning the joint exploitation of an automatic documentation system developed by Euratom.

Fast reactors–the latest moves



The reinforced concrete foundations of the SNEAK *reactor. The structure, a flat-bottomed cylinder, was afterwards* sunk *into the ground.*

Karlsruhe: The combined fast-thermal *STARK* reactor went critical a few months ago. The *SUAK* subcritical fast assembly is completed. The foundations of the *SNEAK* zero energy fast assembly are finished and work has started on the installation of its containment shell.

SNEAK will probably be equipped with an electromagnetic control rod insertion system. This is a new system, which promises to be much quicker than the traditional compressed-air or spring devices. A first prototype is at present undergoing tests.

Cadarache: The sodium pumps for the 1 MW and 10 MW loops at Cadarache—a true-size mockup of the *RAPSODIE* reactor circuits—have now completed 10,000 hours trouble-free operation.

It is planned to run *RAPSODIE* on a mixed oxide fuel (UO_2-PuO_2). A preliminary set of 10,000 pellets has been fabricated and was found to require no finishing prior to cladding. The fabricating process may now therefore be regarded as needing no further adjustments.

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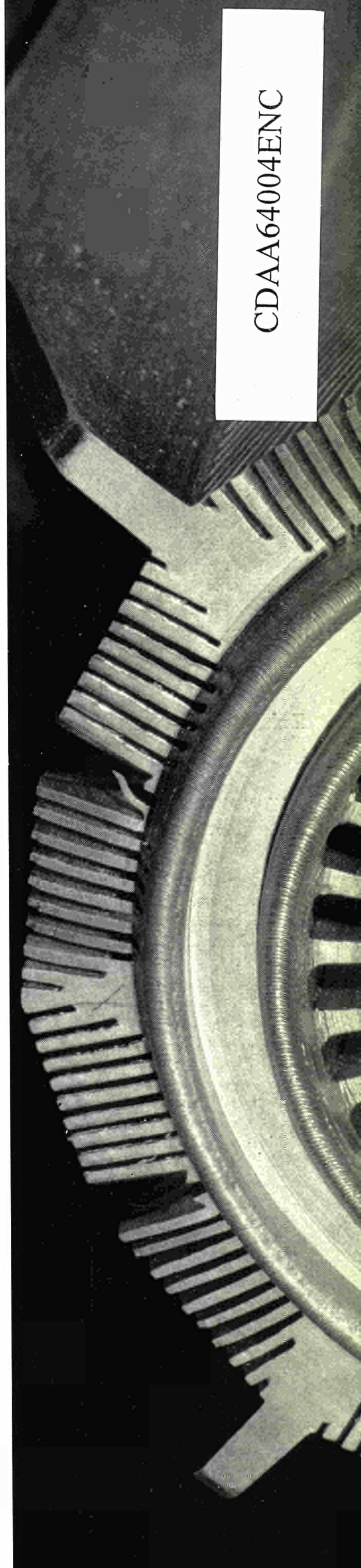

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